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SOVIET SATELLITE GEODESY

BASIS AND STATUS OF SOVIET LASER GEODESY AND LONG-BASE LINE INTERFEROMETRY

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This is a survey of Soviet developments in satellite geodesy, presented in the following sections: survey of Soviet literature; observation and tracking stations; space triangulation networks; cameras used for satellite geodesy; laser geodesy; and long-baseline interferometry. Four appendices are included.

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SOVIET SATELLITE GEODESY

Basis and Status of Soviet Laser Geodesy and Long-Base Line Interferometry

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INTRODUCTION

Any attempt to collect, systematize and analyze the Soviet scientific and technical literature relating to any subject field is a challenging, time-consuming and often frustrating operation. The collection of geodetic and satellite geodesy literature is much more complicated than normally is the case in preparing state-of-the-art reports dealing with non-Soviet publications. This is in large part attributable to the fact that many of the most important Soviet publications are frequently unavailable in the United States, either because the materials were originally published in very limited editions, or were classified by Soviet authorities as "sensitive" data. The problem is further complicated by conditions existing in the U.S. itself, particularly during the past few years, when for a variety of reasons (mainly budgetary), the funds available to the libraries of the U.S. Government agencies, universities, societies and research institutions for the purchasing, processing and dissemination of Soviet publications have been significantly reduced. In addition, the libraries of some institutions either are understaffed or are not readily accessible to the general public.

The result has been that in preparing the present report on Soviet satellite geodesy, many publications known to have been published in the Soviet Union have been determined to be unavailable in U.S. libraries--libraries which normally might be expected to possess such materials. Even in the matter of serial publications, and despite the cooperative efforts of the staffs of many libraries, attempts to locate "missing issues" have been unsuccessful.

With as many materials obtained as possible, the problem then reduced to the systematization and analysis of the available data. Very quickly it became obvious that the Soviets had never released for publication a complete catalog of their satellite observation stations, listing the geographic, geodetic or astronomic positions of these stations, their equipment, personnel and their intracontinental and extracontinental networks, established either by synchronous photographic or combined photographic and laser observational methods. Comparison of the available Soviet data with such sources as the COSPAR Information Bulletin and its COSPAR World List of Satellite Tracking Stations, revealed that these sources, while very useful in some cases in identifying and locating some stations, were also incomplete and out-of-date. These circumstances pointed up the need for collecting as many of these data as possible and resulted in the preparation of the following parts of this report: Part II, Soviet Satellite Observation and Tracking Stations and Their Equipment; Part III, Major Space Triangulation Networks; and Part IV, USSR and East European Cameras Used for Satellite Geodesy Purposes. Admittedly, the information contained in these sections is still incomplete because of the aforementioned reasons, and because many of the data are, by their very nature, out of date either before or shortly after their publication in the Soviet scientific press. The author hopes that these chapters may be of value for reference purposes.

Parts IV and V contain information on satellite tracking cameras and on the early lunar and Lunokhod-I laser experiments, topics that specialists in these fields might consider as already well known. Analysis of the available data, however, indicated that different authors, and sometimes the same authors writing in different publications, gave conflicting data in describing instruments, components, observation methods and measurement results. These discrepancies are generally of minor importance but they illustrate a characteristic of many Soviet technical publications, namely, poor editing or reporting of numerical data. They also point up the danger of accepting data from any single paper as accurate information.

Since information obtained solely from the Soviet scientific and technical literature was not, and probably never will be, adequate for the compilation of an up-to-date and complete state-of-art study of Soviet satellite geodesy, Soviet data in some cases had to be supplemented and/or verified from non-Soviet literature, mainly of East European origin. For example, detailed information on the space triangulation program, "Project WESTA", was obtained from the Polish literature and the most recent information on the locations at which the Soviet AFU-75 tracking cameras have been installed was found in a journal published in East Germany. The journal, Space Science Reviews, published in Amsterdam, also provided tracking camera site information not furnished in the Soviet literature.

Finally, as a result of the increased participation of Soviet scientists and institutions in international projects, information on the results of Soviet research not released for publication in the Soviet Union occasionally has been presented at international meetings and published in their Proceedings. Time restrictions did not permit exploitation of either of these types of sources.

Bibliographic references to the Soviet literature used in this report are listed at the ends of Parts II-VI. Abbreviations frequently used throughout the paper are:

AES - artificial earth satellite

D.M.E. - distance-measuring equipment

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ASMCS Library, University of California, Berkeley, California

Atmospheric Sciences Library, NOAA, Silver Spring, Maryland

Dartmouth College Library, Hanover, N. H.

Lincoln Laboratory Library, Massachusetts Institute of Technology, Lexington, Massachusetts

NASA Goddard Space Flight Center Library, Greenbelt, Maryland

NASA Headquarters Library, Washington, D. C.

National Academy of Sciences Library, Washington, D. C.

Naval Observatory Library, Washington, D. C.

Scripps Oceanographic Institute Library, La Jolla, California

Smithsonian Astrophysical Observatory, Cambridge, Massachusetts

PART I

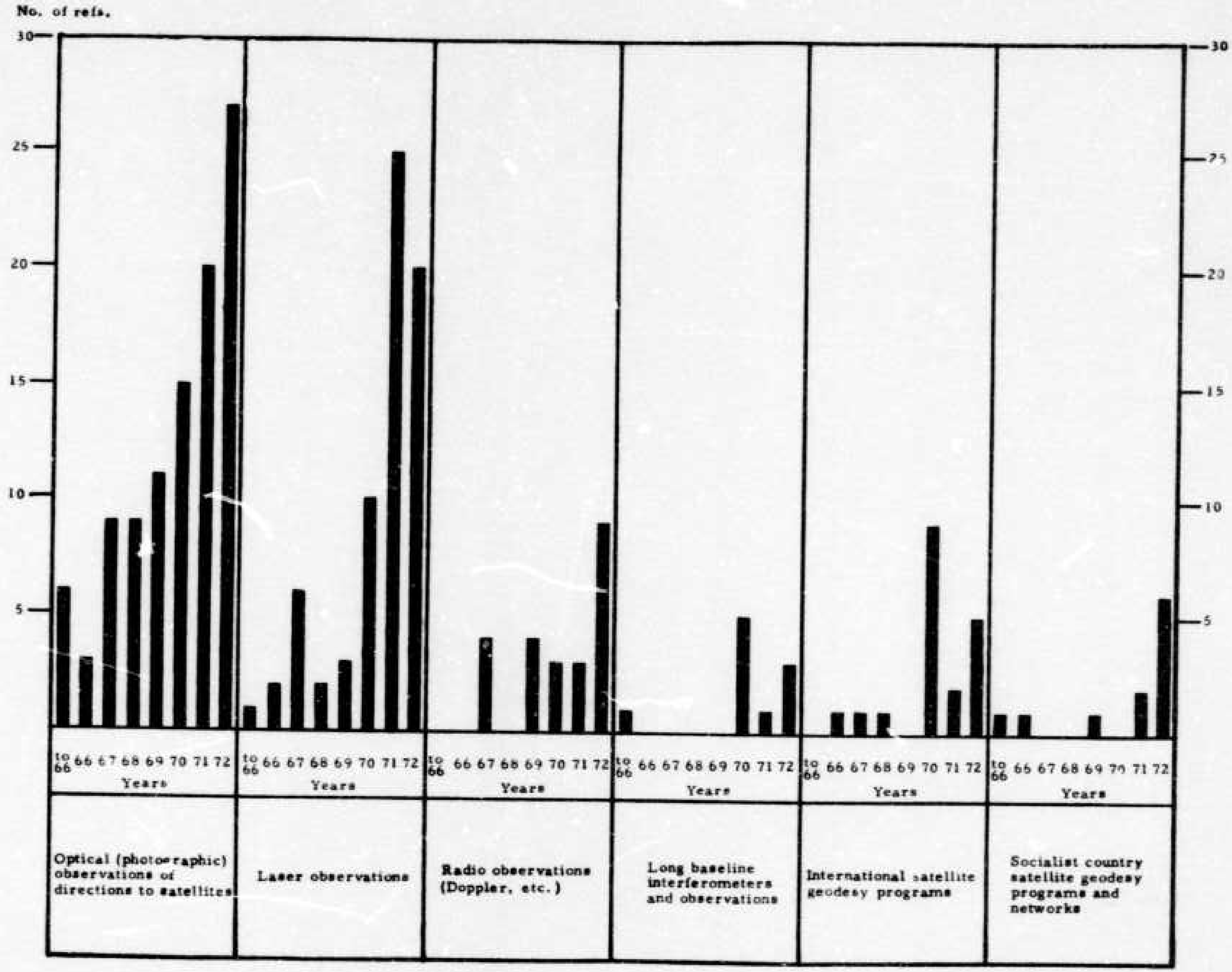
SURVEY OF SOVIET LITERATURE ON SATELLITE GEODESY

Information published by the Soviet Union on their research and development in the field of satellite geodesy is contained in a wide variety of sources ranging from newspapers to the most detailed theoretical scientific monographs. Since some of the applications of satellite geodesy are of potential military significance, some Soviet publications are assigned security classifications and foreign dissemination is thereby prohibited. This policy is also adopted for the publication of certain instrument patents with the result that some patents are published many years after the issuance of the patent or, indeed, are never published at all. Other devices used to restrict the foreign dissemination of technical publications include the elimination of the foreign distribution of otherwise unclassified publications (e.g., the Trudy's of some scientific or technical institutes) and, finally, the publication of very small editions of some of the more important scientific journals and periodicals, thus effectively limiting the supply of issues available to foreign subscribers.

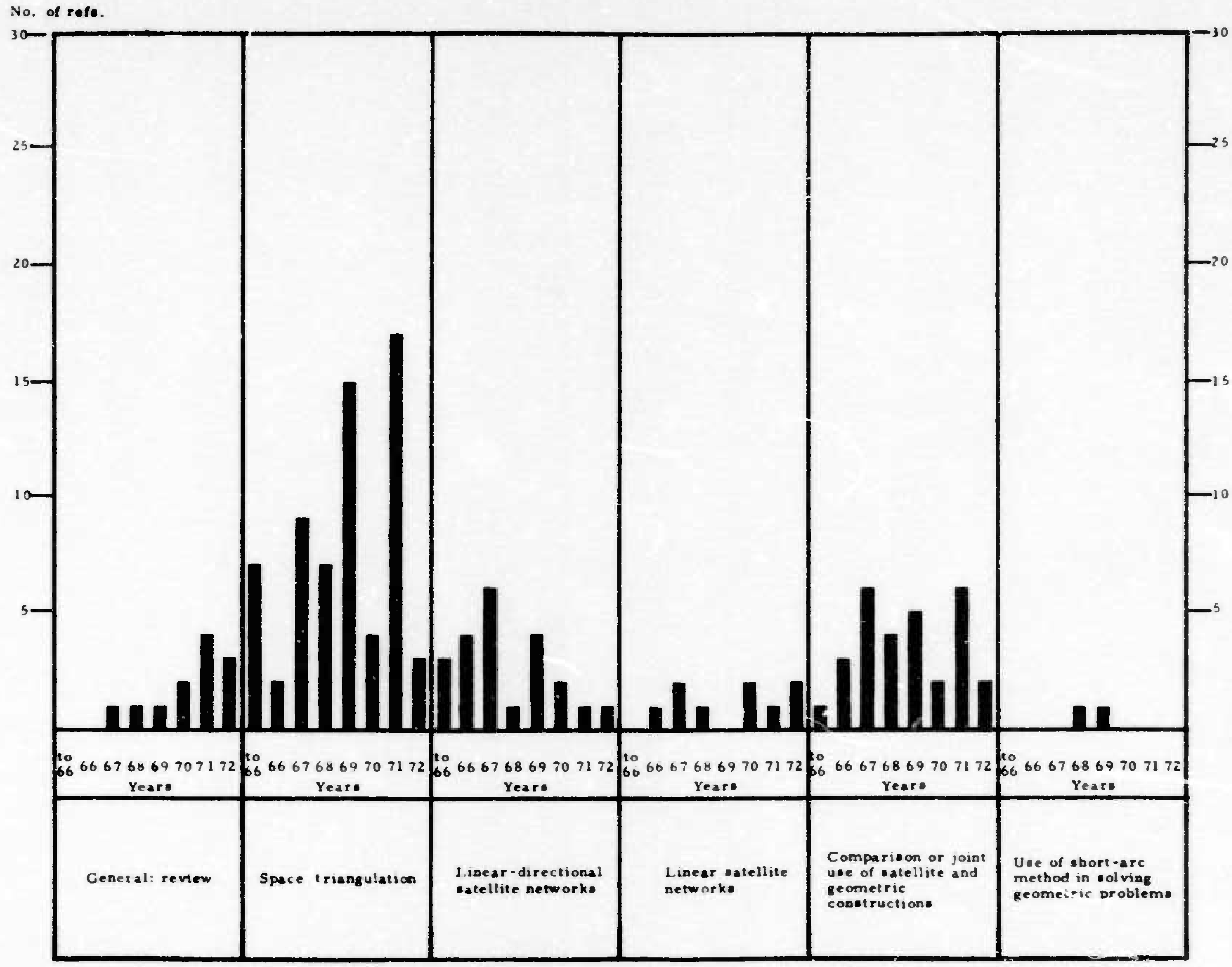
All of these factors, together with other conditions presently obtaining in the United States itself (reduced research budgets, reduced funds for library staffs and purchases, etc.) have combined to produce the result that no U. S. library possesses complete sets of several of the required journals or periodicals and any attempt to gather information on the availability of the "missing issues" is a time-consuming, and sometimes futile, operation.

Despite these drawbacks, however, a rather considerable body of information (approximately 1100 bibliographic references, covering for the most part the 1966 through 1972 period) has been located and evaluated for the purposes of the present report. Approximately 650 of these references taken from the geodetic, astronomic, geophysical, optical, radio engineering and space sciences literature, were selected as significant contributions to an investigation of the study of Soviet satellite geodesy.

A general picture of the quantitative and time-wise emphasis placed by Soviet authorities on various aspects of satellite geodesy can be obtained from the following seven tables, which have been compiled from these 650 references (Tables I through VII). In making this compilation, assignment of some references to any single category was impossible, since many papers dealt with several aspects of the major problem. In such cases, an attempt was made to assign these papers to the categories (7 major topics and 41 subtopics) most directly applicable to the more specific topic of the present report, namely, Soviet laser geodesy.



I. METHODS OF PRECISE OBSERVATIONS OF ARTIFICIAL EARTH SATELLITES



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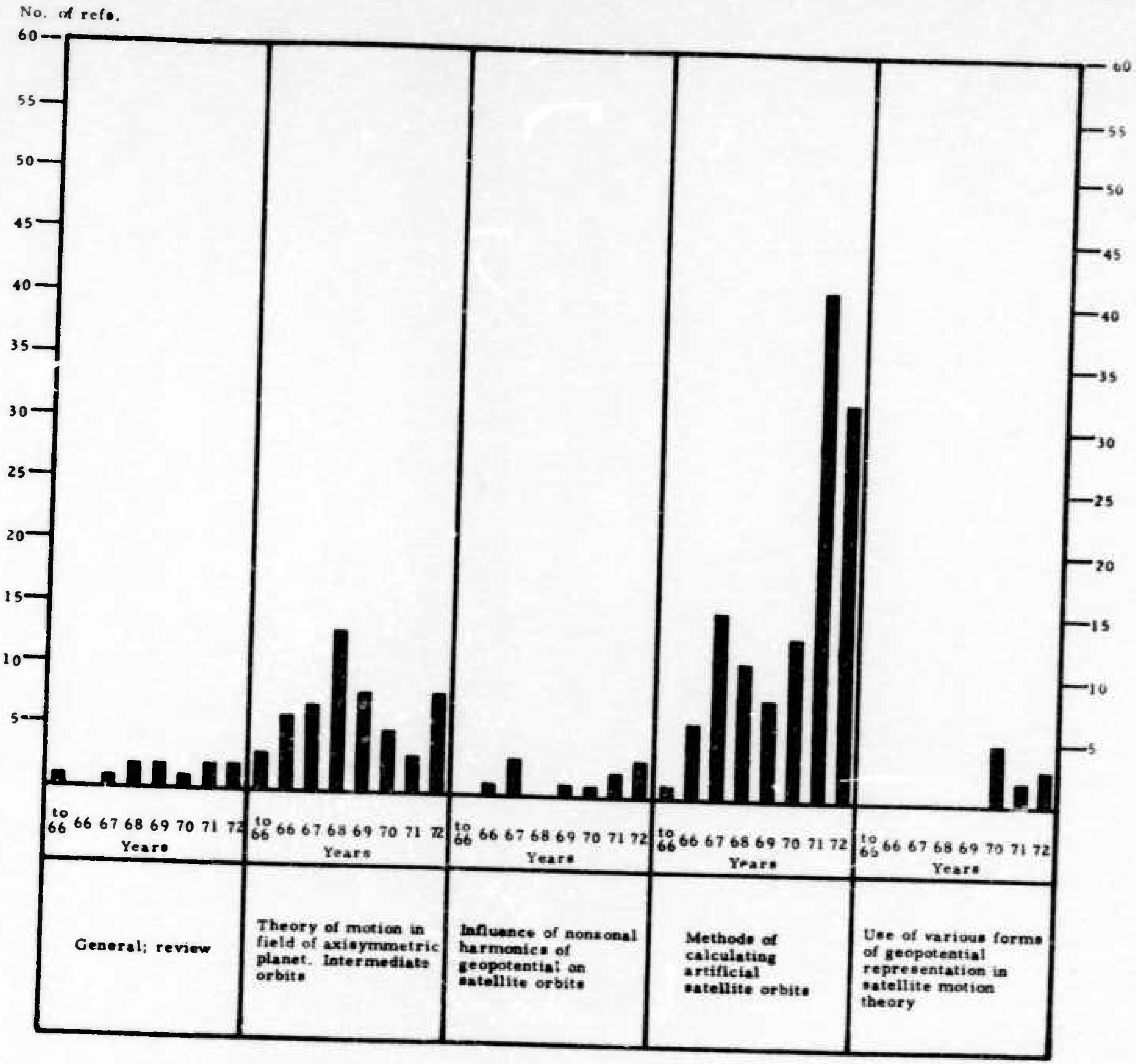

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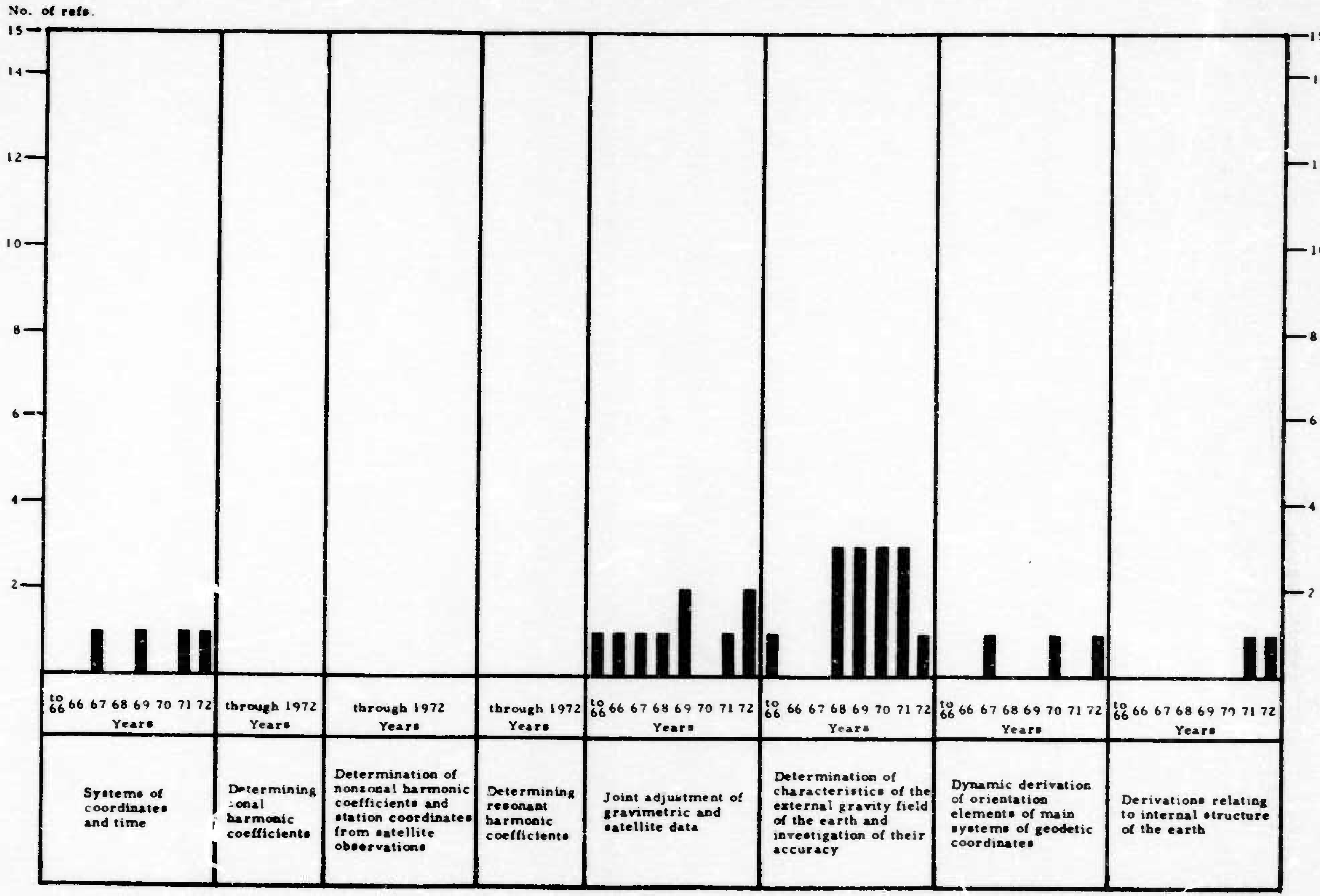

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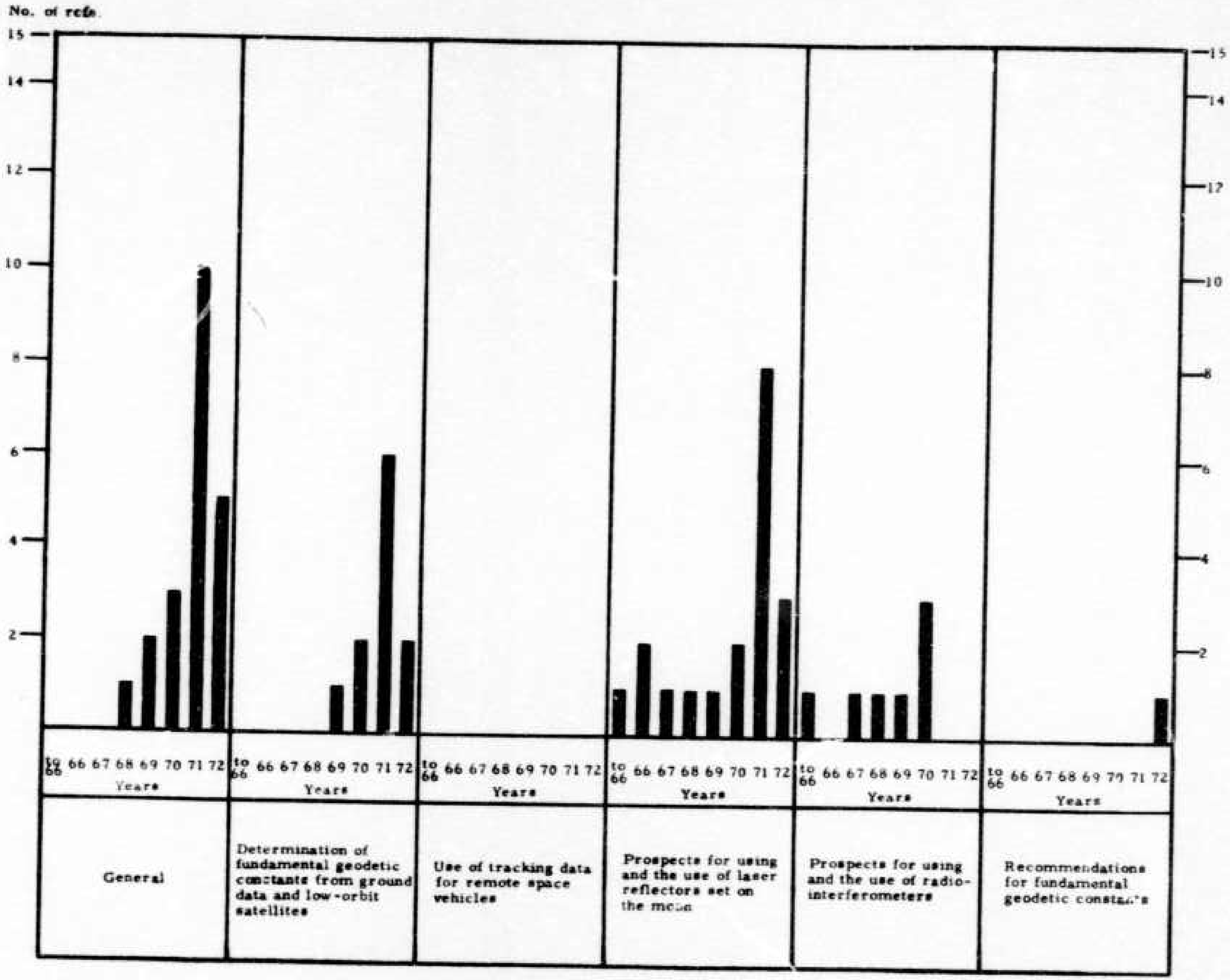
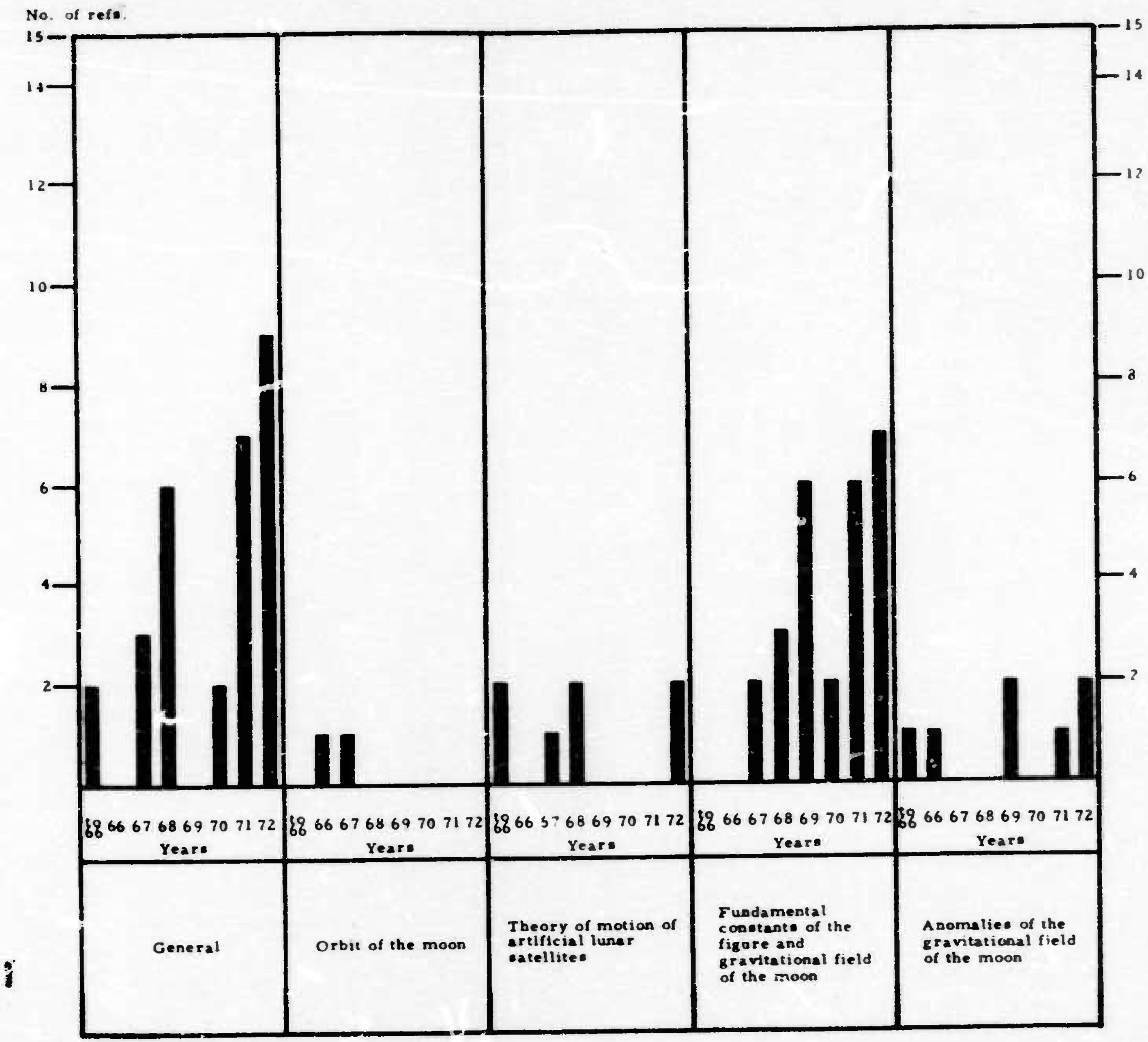
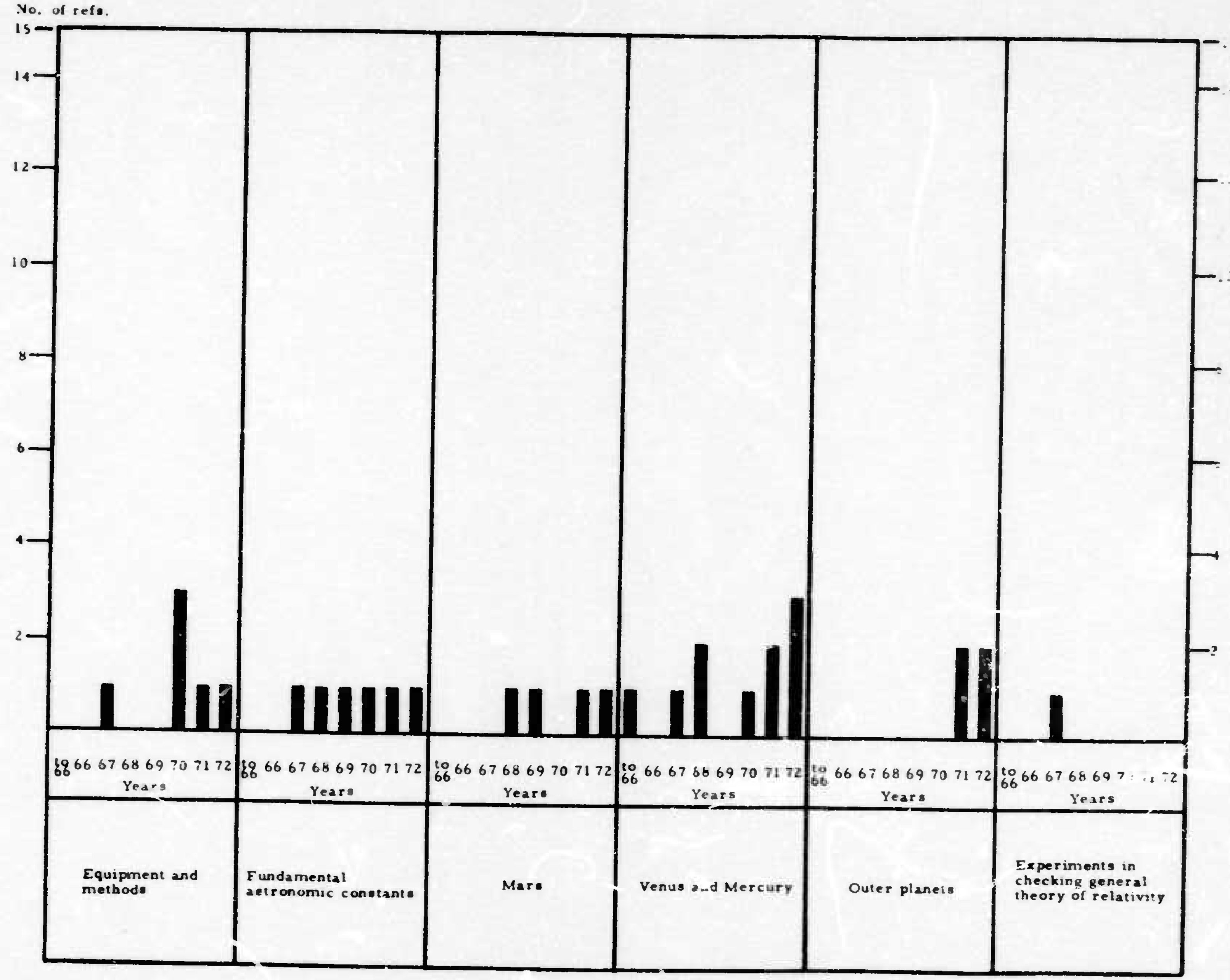


V. FUNDAMENTAL GEODETIC CONSTANTS



VI. ORBIT, GRAVITATIONAL FIELD AND FIGURE OF THE MOON



VII. DETERMINATION OF THE FIGURES AND GRAVITATIONAL FIELDS OF MAJOR PLANETS

References used in the tabulated analysis also include a numerically relatively insignificant but qualitatively important category of papers that have become available to American scientists in the past few years in ever-increasing volume as the result of the increased participation of Soviet scientists in international projects (e.g., ISAGEX, lunar laser ranging experiments, long-base line interferometer measurements, etc.). The publications resulting from these cooperative efforts are of two general types: 1) papers presented in various languages by scientists from the USSR and the socialist countries at international meetings, and 2) papers published under the joint authorship of Soviet and non-Soviet scientists representing the cooperating nations. Regrettably, the time factor precluded thorough analysis of these publications and only the most pertinent (and available) could be included as a part of the present report. In addition, the assumption was that American scientists involved in these studies are fully knowledgeable about these publications and their contents.

Fewer than 100 references, containing information on the status of the development of Soviet laser geodesy, have been located to date in the literature of the Soviet Union or of the socialist countries. These references cover a large variety of topics ranging from the most theoretical discussions of methodology to the technical applications and instrumentation. They also include papers dealing with such topics as the theory and applications of laser beam propagation within and outside the atmosphere, the practices used and the results obtained in the Soviet Union in laying out space networks by conventional, combined optical and laser, laser, and laser-interferometer methods. Frequently, references are repetitious, almost identical information appearing in several journals. Because of this divessity, references to these topics are included in many of the categories represented in Tables 1 - 7 (A, all subtopics; B, 1, 2, 3; D, 1; E, 1, 3, 4; F, 1, 3, 4, 5; and G, 1, 2).

The seven tables indicate that over the 1966-1972 period major and increasing emphasis has been placed on both optical (photographic) and laser observations (singly and in combination), space triangulation methods and constructions, methods of computing AES orbits, selenodesy, and the development of domestic and international geodetic networks from AES photographic and laser observations. The apparently lesser (and later) emphasis on radio- and interferometer methods and instrumentation is due, at least in part, to the unavailability of certain publications known to exist and for which only abstracts are available. Such subjects as dynamic geodesy, i.e., the joint adjustment of gravimetric and satellite data and investigations of the characteristics of the external field of the earth, of the moon and some planets, are also emphasized in the Soviet literature. The same is true of the ever-increasing volume of papers being published in the literature on geodetic, astronomic and geophysical investigations of the major planets and on investigations being carried out to determine optimum locations for "astroclimatic observatories", which in some cases also are engaged in "satellite observations" mainly with long-base line radiointerferometers (see Part II - on Soviet satellite observation installations).

However, since many of these topics are only indirectly related to the field of laser geodesy and each would require a separate report of a size comparable to that of the present report, no attempt has been made here to analyze these publications or to include these references in the bibliography.

PART II. SOVIET SATELLITE OBSERVATION AND TRACKING STATIONS AND THEIR INSTRUMENTATION.

Examination of all available Soviet reference materials (ranging in character from local newspapers to scientific books and periodicals), which contain information on the number and types of satellite observation and tracking stations, their geographic, geodetic or astronomic coordinates and instrumentation, revealed that Soviet authorities either have never compiled or at least have never released for dissemination abroad, complete or up-to-date catalogs or listings of these types of data. Further examination also showed that even after the Soviet Union had become a participating member of the COSPAR satellite geodesy programs, pertinent information of this kind was not always reflected in the Lists of Satellite Tracking Stations, published irregularly in the COSPAR Information Bulletins. Because of these deficiencies, an attempt has been made in the present report to compile and tabulate relevant data collected from many Soviet literature sources (see Table 1).

This Table shows that there are at least two major types of satellite observation facilities in the Soviet Union:

1) Stations at which optical observations are made, including the so-called "visual"* and photographic stations and laser-photographic stations; and

2) radioastronomic observatories, from which long-base line interferometer studies have been carried out.

---

* i. e., stations reporting satellite sightings.

There is a possibility that a third category of facility, presently referred to as astroclimatic stations or observatories, may soon be or already are (?) equipped with instruments suitable for satellite tracking and geodetic observations. The identification of potential sites for these observatories, i.e., sites offering optimum "seeing" conditions, has been the purpose of many expeditions sent to the high-mountain areas along the southern boundary of Central Asia during the past twenty years. According to the Soviet literature encountered in the course of the present study, these observatories are expected to be equipped with powerful telescopes and a variety of related instruments that would permit sophisticated deep space astronomical investigations (quasars, pulsars, etc.). These same sites, equipped with satellite tracking cameras, radiotelescopes and laser-ranging apparatus, would be excellent satellite tracking station locations, and would be especially important for radiotelescopes adapted for use in making long-base line interferometer measurements. This possibility is of particular interest because the mountainous areas being investigated extend over a long east-west line from the Crimea on the west (Simeiz, where the observatory is already equipped with most of the equipment required for satellite geodesy investigations), eastward across the Turkmen, Uzbek, Tadzhik, Kirgiz and Kazakh Republics in an east-west belt between 38°-45° N. Lat.

Time limitations have prevented a thorough investigation of this type of facility. However, a brief history of the project and some of the recently published results obtained from field investigations carried out in the Tadzhik and Uzbek Republics are included in the present report as Appendix D.

Literature sources providing satellite observation data:

1. Ephemeris data -- at one time obtained at approximately 100 "visual" and, to a lesser extent, photographic stations -- are published in the USSR Astronomical Council's publication, Rezul'taty nablyudeniy sovetskikh iskusstvennykh sputnikov Zemli, published in Moscow* until 1970-1971. At this time the number of stations reporting these data apparently was greatly reduced; 34 of the stations reporting in 1966 did not provide these data in 1971.

2. Observational data used for scientific and geodetic purposes were obtained mainly at the photographic stations and are, for the most part, published in the USSR Astronomical Councils' periodical Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli. Additional data and theoretical studies are reported in the Trudy's, Nauchnyye informatsii's, and Byulleten's of several astronomical observatories, and astronomical, physics, electronic and geodetic institutes, as shown in the several lists of references appended to each section of this report.

Training and education of station personnel

Effective execution of the various types of satellite observation and tracking programs carried out at these stations has required

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* Presently being published in Ryazan.

that large numbers of well-trained personnel be available. Intensive training programs were carried out by or under the direction of the USSR Astronomical Council and, to a lesser extent, by some of the major astronomical observatories, such as the Main Astrononiical Observatory (GAO) at Pulkovo. A partial analysis of these programs is presented in Appendix C.

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long	H. (in m)	Equipment
1 (1001)	Abakan (Ped. Inst.)	(V) 53°43′16″	91°26′18″	247 [1]	Small cameras [1] [31]
2	Alma-Ata (Kazakh. Gos. Univ.) (See also station no. 67)	(V)+43°14′47″	76°55′36.″9	850 [1]	
3 (1003)	Abastumani (Astrofiz. Observ.),	(V)41°45′18″	42°49′30″	1600 [1]	
	AN Gruz SSR	(P)41°45′18″	$2^h51^m18^s.0$ E	1650 [2, p. 11]	NAFA-3c/25 [2]. 70-cm
	Kanobili Mt.			1700 [42]	meniscus telescope [42]
4	Arkhangel'sk (Ped. Inst.)	(V)64°32′	40°34′	10 [1]	"Leningrad" camera [26, p. 26-27]
5	Astrakhan' (Ped. Inst.)	(V)46°21′	48°03′	-20 [1]	
6	Ashkhabad (Univ.)	(V)37°57′19″	58°21′	- [1]	Small cameras [1] [31]
	(Inst. fiz. i geofiz., AN Turk SSR)	(P)37°57′19″	$03^h53^m23^s$	234 [7, p. 20-21]	NAFA-3c/25 [4 p. 18]
7	Baku	(V)40°22′	49°49′30″	84±10 [1]	
		(P)40°21′30″	$-3^h19^m18^s.0$	84±10 [8, p. 19]	NAFA 3c/25 [8, p. 16-19]; AT-1 · "Smena-4" camera [13].

Table 1. Locations and Equipment of USSR Satellite Observation Stations

Table 1 (continuec

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
8	Barnaul (Ped. Inst.)	(V)53°19'53".6	33°45'57".8	186.4 [1]	
9	Batumi (Ped. Inst.)	(V)41°39'	41°37'	-1.5 [1]	Small cameras[1] [31]
10	Blagoveshchensk na Amure (Ped. Inst.) (See also station no. 86)	(V)50°15'32"	127°32'23"	128 [1]	Small cameras[1] [31]
11 (1011)	Bukhara (Ped. Inst.)	(V)39°46'43"	64°24'42"	228 [1]	
12	Vil'nyus (Astronomic Observ.(?)	(V)+54°41'01"	25°15'19".5	138 [1]	
13 (1013)	Vladivostok (Dal'nevost. Gos. Univ.)	(V)43°07'	131°53'9"	65 [1]	
14	Vologda (Ped. Inst.)	(V)59°13'20"	39°53'25"	150±10 [1]	Small cameras[1] [31]
15	Voronezh (Univ.)	(V)51°39'21"	39°12'24"	156 [1]	

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
16	Gor'kiy (Lat. Sta.) (See also Station No. 50)	(V)56°15'33"	43°59'15"	163 [1]	
17 (1017)	Dnepropetrovsk (Gos. Univ.)	(V)48°26'05.9	35°02'42"	144 [1]	AT-1 [6, p. 19-22]; "Leningrad" camera, mounted on AT-1 [18, p. 13-20]; small cameras [31]
18	Yerevan (Univ.)	(V)40°11'	44°30'	950 [1]	NAFA-3c/25 [14, p. 15-17]; AT-1 [18, p. 11]; TZK [18, p. 11]; VAU- "installed near Yerevan" Arm SSR [39, p. 335].
19	Irkutsk (Univ.)	(V)52°16'25"	104°16'52.5	437 [1]	
		(P)52°16'44.1	104°20'43.5	468 [1]	
20	Kazan' (Univ. Sat. Obs. Sta.)	(V)55°47'23.9	49°07'15.45	79 [1]	
		(P)55°50'20.2	$-3^h15^m15^s.74$	98 [5, text, p. 18]	NAFA 3c/25 [5, text, p. 18]
	(Univ., Astron. Obs. im Engel'gardta)	(P)55°50'18"	$3^h15^m15^s.7$	98 [2, text, p. 11]	NAFA 3c/25 [2, text, p. 11]
21	Karaganda (Ped. Inst.)	(V)49°49'07" ±5"	73°05'02" ±1"	556±1 [1]	
22	Kyzyl-Orda (Ped. Inst.)	(V)44°50'08	65°30'25"	127 [1]	Small cameras[1] [31]

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
23	Kiev (Univ. im. Shevchenko) (Astron. Observatory)	(V)$50^{\circ}27'11''.43$	$30^{\circ}30'07''.05$	184 [1]	
		(P)$50^{\circ}27'11''.43$	$2^{h}2^{m}0^{s}.47$ E	184 [3]	NAFA-3c/25 [3, text, p. 15]
24 (1024)	Kishinev (Univ.)	(V)$46^{\circ}57'22''$	$28^{\circ}51'57''$	190 [1]	
25	Komsomol'sk (Ped. Inst.) (na Amure)	(V)$50^{\circ}32'27''$	$137^{\circ}01'26''.5$	24 [1]	AT-1 [2]; small cameras[1] [31]
26	Krasnoyarsk (Ped. Inst.)	(V)$56^{\circ}01'.5$	$92^{\circ}91'.5$	150 [1] above Baltic	
27 (1027)	Krasnodar (Ped. Inst.)	(V)$45^{\circ}01'44''.2$	$38^{\circ}58'42''.17$	40 [1]	NAFA-3c/25, NAFA-3c/50, AT-1 [22, p. 9-11]
28	Krym, (Crimean Astrofiz. Obs., AN SSSR) (Sometimes referred to as Simferopol' in early (1957-8) publications)	(V)$44^{\circ}43'.7$	$34^{\circ}01'30''$	568.8 [1]	Small cameras[1] [31]; Zenit-C [16, p. 33-34]
		(P)$44^{\circ}43'42''$	$2^{h}16^{m}06^{s}$	568.8 [7, p.22]	NAFA-3c/25 [7, p. 22]; 2.6 m reflector telescope [29, p. 22-24]; radio telescope, 22-m parabolic antenna [43]; laser-ranging equipment (Simeiz) [37].
		$44^{\circ}43'42''$	$34^{\circ}01'$		
		(P)$44^{\circ}43'42''$	$34^{\circ}01'$	- [3, p. 5]	AT-1 [3, p. 3-7]
29 (1029)	Kurgan (Ped. Inst.)	(V)$55^{\circ}26'$	$65^{\circ}21'7''$	75 [1]	

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
30 (1030)	Leningrad (Sat. observ. sta.)	(V)$59^{\circ}56'38''.4$	$30^{\circ}16'15''$	15 [1]	Small cameras [1] [31]
31 (1031)	L'vov (Sat. observ. sta.)	(V)$49^{\circ}49'57''.6$	$23^{\circ}46'46''.95$	330 [1]	
	Astron. Observ.	(P)$49^{\circ}49'57''.6$	$1^{h}36^{m}07^{s}.03$ E	330 [5, text, p. 21]	NAFA 3c/25 [5, text, p. 21]; NAFA 3c/25 C[12, p. 7-10]; TZK [22, p. 6]; AT-1 [22, p. 20]; NAFA MK-75 [44]
32	Perm' (Univ.)	(V)$58^{\circ}00'.4$	$56^{\circ}11'.5$	98.4 [1]	
33 (1033)	Minsk (Univ. Sat. Observ. sta.)	(V)$53^{\circ}58'40''$	$27^{\circ}32'45''$	230 [1]	
34	Moscow, GAISh	(V)$55^{\circ}41'58''$	$37^{\circ}32'40''.5$	200 [1]	NAFA-3c/25 [8]
		(P)$55^{\circ}41'57''.4$	$37^{\circ}32'41''.72$	202.1 [40]	
35 (1035)	Novosibirsk (NIIGAiK)	(V)$55^{\circ}02'21''$	$82^{\circ}55'30''$	180 [1]	AT-1 [13, p. 8-11]; NAFA-21 [18, p. 12-13]; TZK combined with "Turist" camera [20, p. 24-26]
36	Odessa (Astron. Observ.)	(V)$46^{\circ}28'37''$	$30^{\circ}45'30''$	53 [1]	
		(P)$46^{\circ}28'38''.4$	$02^{h}03^{m}01^{s}.93$ E	53 [2, text, p. 12]	NAFA 3c/25 [2, text, p. 12]

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
37	Omsk (Ped. Inst.)	(V)54°59′	73°22′	101.4 [1]	**FED-2-type camera [6, p. 24]; small cameras** [illegible]
38	Petrozavodsk (Univ.)	(V)61°47′12″	34°21′30″	100 [1]	
39 (1039)	Pulkovo (Sat. Obs. Sta.), GAO	(V)59°46′14.″5	30°19′37.″95	75 [1]	ShT-1 **Pilot-balloon theodolite; AT-1 [3, text, p.** [illegible]
		(P)59°46′13.″7	30°19′38.″5	76.5 [41, p. 64]	**NAFA-3c/25 [3], NAFA-3c/25C[5, p. 1]; standard azimuthal camera (F = 253.5 mm) [10, p. 18];** [illegible] **(moving film) [16, p. 20-25]; FAS [38, p. 14]**
40 (1040)	**Riga (Sat. observ. sta.) (See Station No. 84)**	(V)56°56′56.″2	24°03′39.″75	+8 [1]	**AT-1 [2], TZK [22]**
41	Rostov-na-Donu (Univ.)	(V)47°13′31″	39°42′40″	68 [1]	
42 (1042)	Ryazan' (Ped. Inst.)	(V)+54°38′05″	-39°45′10″	120 [1]	AT-1 [3, text p. 9-12]; TZK [19, p. 14-21]
43	Samarkand (Uzbek Univ.)	(V)39°39′30.″6	66°57′22.″7	689 [1]	Small cameras[1] [31]
44	Saratov (Univ.)	(V)51°32′14.″2	46°00′40.″05	85 [1]	

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
45	Sverdlovsk (Astro. Obs., Ural. Univ.)	(V)56°49'25."8	60°36'28."8	274 [1]	
		(P)56°49'25."8	$4^h2^m25.^s92$	243 [2, text, p. 10]	NAFA-3c/25 [2, text, p. 10]
		(P)56°49'25."8	$4^h2^m25.^s92$	274 [4, text, p. 19]	
46	Smolensk (Ped. Inst.)	(V)54°46'45"	32°03'45"	240 [1]	
47	Stalinabad (Univ.) (See also sta. No. 68)	(V)38°34'32"	68°48'34."5	833.85 [1]	
48	Stalingrad (Ped. Inst.)	(V)48°41'.8	44°31'.5	50 [1]	
49	Syktyvkar (Ped. Inst.)	(V)61°38'41"	50°51'51"	129.5 [1]	
50	Gor'kiy (Ped. Inst.) Listed as Tashauz in [3] (See also sta. no. 16)	(V)56°19'36"	44°0'15"	139 [1]	
51 (1051)	Tartu ("temporary" station)	(V)58°22'47."16	26°43'17."7	67 [1]	
	Tartu (Univ.)	(P)58°22'47"	$1^h46^m53.''2$	68 [9, p. 24]	NAFA-3c/25 [9, p. 24]
	(Astron. Observ., AN Est SSR)	(P)58°22'47."56	26°43'19."47E	68 [3, text]	"Telemar" (F = 75 cm, D:F = 1:6.3 [3, text, p. 15]; NAFA-6/50 [17, p. 7-10]
	Inst. fiziki i astronomii, AN Est SSR (See also sta. no. 83)	(P)58°22'48	26°43'19"	68 [2, text, p. 13]	
					Lun-3 (refractor telescope with azimuthal mount [11, p. 1-6]; OT-10 theodolite [8]; AZT-12 refl. telescope [46]

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates: Lat.	Long.		Equipment
52	Tashkent (Univ.) = Obs. Sta. Central Asia State Univ. Astron. Obs., AN Uzb SSR	(V)$41^{\circ}21'00.''1$	$69^{\circ}11'12.''2$	440.8 [1]	NAFA 3c/25 [4, p. 18] - small cameras [1] [31]
		(P)$41^{\circ}19'33.''3$	$4^{h}37^{m}10.^{s}476$	476 [6]	NAFA 3c/25 [6, p. 27]; AFU-75 [47]
53 (1053)	Tbilisi (Univ.)	(V)$41^{\circ}42'41.''3$	$44^{\circ}46'52.''5$	450 [1]	
54	Tomsk (Univ. obs. sta.)	(P) and (V)$56^{\circ}28'06.''3$	$84^{\circ}56'48''$	114.4 [1]	NAFA 3c/25 (F = 252.3 mm) [16, p. 25-26]
55 (1055)	Uzhgorod (Univ. Obs. Sta.)	(V)$48^{\circ}38'03''$	$22^{\circ}18'01.''2$	- [1]	Small cameras [1] [31]
		(P)$48^{\circ}38'03''$	$1^{h}29^{m}12.^{s}1$	190 [5, text, p. 22]	NAFA 3c/25 [5, p. 22]; AFA-MK [10, p. 19]; KPP [21, p. 6-8]; UF ISZ-25-2 (focal length 253.33 + 0.05 mm) [30, p. 19]; AFU-75 [29, p. 10] FAS [38, p. 14]; laser ranging equipment [49]
		(P)$48^{\circ}38'04.''6$	$22^{\circ}17'57.''9$	189.2 [41, p. 64]	
		(P)$48^{\circ}38'$	$22^{\circ}18'$	[29, p. 21]	
56 (1056)	Ulan-Ude	(V)$51^{\circ}50'30''$	$107^{\circ}34'30''$	416 [1]	
57	Ufa (Bashkir Gos. Univ.)	(V)$54^{\circ}43'13.5''$	$55^{\circ}55'26.''5$	196.87 [1]	

Table 1 continued.

Sta. No.	Station Name (Affiliation)	Lat.	Long.		Equipment
58	Frunze (Univ.)	(V) 42°53'8"	74°35'15"	729.5 [1]	
59	Khabarovsk (Univ.)	(V) 48°29'.2±0'.1	135°04'.8 ±0'.1	125±5 [1]	
60 (1060)	Khar'kov (Astro. Obs.)	(V) 50°0'10".9	36°13'57"	138.5 [1]	AT-1 [7, p. 15-16]; NAFA 3c/25 [12, p. 23-26]
	Ped. Inst.				AT-1 [2]
61	Chardzhou (Ped. Inst.)	(V) 39°05'	63°39'	190 [1]	
62 (1062)	Chernovtsy (Univ.)	(V) 48°17'	25°56'	240 [1]	TZK [18, p. 6-8]; small cameras[1] [31]
63	Orenburg (Ped. Inst.)	(V) 51°45'30"	55°06'25"	130 [1]	Small cameras[1] [31]
64	Chita (Ped. Inst.)	(V) 52°01'30"	113°30'	681 [1]	

Sta. No.	Station Name (Affiliation)	Station Coordinates: Lat.	Station Coordinates: Long.		Equipment
65 (1065)	Yuzhno-Sakhalinsk (S. Sakh. Sci. Res. Sta.)	(V)46°56'44"	142°42'15"	38 [1]	Small cameras[1] [31]. AT-1 [2, text, p. 5-7]
		(P)46°57'	142°42'	[2?, p. 21]	FAS camera [38, p. 14], AFU-75 [29, p. 10]
66	Yakutsk (Univ.)	(V)62°01'48"	129°37'30"	99 [1]	
67 (1067)	Alma-Ata (Astrofiz. Inst., AN KazSSR) (See also Sta. No. 2)	(V)+43°11'16".62	76°57'27".6	1450 [1]	
		(P)43°11'16"	$5^h7^m49.8$	1450 ± 50 [1, p. 18]	Maksutov meniscus telescope (D = 500 mm, F = 1200 mm) [9]; 20 cm refractor telescope [48]; 70 cm reflector telescope [48]; 50 cm camera "for astrogeodesy purposes" [48]; high-frequency apparatus (electronic-optical rectifiers) [48]; TV equipment for observing moon and satellites [48].
		(P)43°11'16".9 ± 0".6	$5^h7^m49.76 \pm 0^s.04$	1450 ± 50 [9, p. 18]	
68	Stalinabad, (Inst. astrofiz. AN Tadzh SSR) (See also Sta. No. 47)	(V)38°33'39".9	68°46'52".08	820 [1]	
		(P)38°33'39".94	$4^h35^m07.472E$	820 [3, text, p. 16]	NAFA-3c/25; NA-MK-75 camera [35] [3, text, p. 16] NAFA-3c/25C [12, p. 3-7]; VAU [32], at Gissar Observatory
		?38°33'39".94	$-4^h35^m07^s.472$	820 [8, p. 22]	
69	Kungur	(V)57°25'32".96	56°56'48"	140 [1]	
70	Kiev, GAO, AN SSSR.	(V)50°21'55".84	30°29'52".5	184 [1]	
		? 50°21'55".84	30°29'52".5	184±2 [8, p. 1?]	

[1] apparently an error

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.			Equipment
71	Ul'yanovsk (Ped. Inst.)	(V)54°19'12"	48°24'39"	17[illegible]	[1]	
72 (1072)	Astrosovet Sta., Moscow; in 1963 = Zvenigorod Exper. Sta.)	(V)55°45'19."8	37°34'14."25	166	[1]	
		(P)55°45'20"	$2^h30^m17^s.0$	145	[2, text, p. 11]	NAFA-3c/25 [2]; NAFA-3c/25C [14, p. 9-12]; NAFA MK-75 [15, p. 47-48]; NAFA-3c/50-C [27, p. 27]; two AFU-75 cameras [2[illegible], p. 10 and 23]; VAU [29, p. 12]; SBG [34]; FAS [38, p. 14]; AST-452 [34]; laser equipment [34]
	(First located at Gos. Astron. Inst. im. Shternberg-GAISh) in Moscow; moved in 1958 to suburbs near Zvenigorod) [34]	(P)55°41'37.7	36°46'34.0	173.2	[41, p. [illegible]4]	
		(P)55°42'	36°47'		[29, p. 21]	
73 (1073)	Odessa, (Astro. Observ.)	(V)46°28'37"	30°45'30"	53	[1]	NAFA-3c/25 [2, p. 12]
		(P)46°28'38."4	$2^h03^m01.93$	53	[2, p. 12]	
74 (1074)	Ashkhabad, Inst. Fiz. i Geofiziki	(V)37°57'18"	58°20'45"	234	[1]	
	Institut astrofiziki AN Turk SSR	(P)37°57'19"	$3^h53^m23^s$	234	[7, p. 20]	NAFA-3c/25 [7, p. 20]
						NAFA-3c/25 [14, p. 3-6]
75 (1075)	Tashkent (Astro. Observ.,	(V)41°19'30"	69°17'37."05	479	[1]	
	AN Uzb SSR)	(P)41°19'33."3	$4^h37^m10^s.476E$	47[illegible]	[4, text, p. 18]	NAFA 3c/25 [4, text, p. 18]
76 (1076)	TASSR Sta. observ., Kaz. R. R.	(V)+55°50'20."2	48°48'56."1	98	[1]	
	Kazan'. Astro. Observ. im Engel'gardta	(P)55°50'18"	$3^h15^m15^s.7$	[illegible]	[2, p. 11]	NAFA 3c/25 [2, p. 11]
		(P)55°50'20.2	$-3^h15^m15^s.74$	[illegible]	[5, p. 18]	

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.			Equipment
77 (1077)	Nikolayevskoye Otd. GAO AN SSSR	(V)46°58'18."0	31°58'26."25	518	[1]	
		(P)46°58'18."0	$-2^h07^m53.^s75$	518	[2, text, p. 13]	NAFA-3c/25 [2, text, p. 13]
		(P)46°58'20."0	31°58'22."2	518	[41, p. 64]	
78 (1078)	Olekminsk [2] Listed as Mogilev [10] Listed as Yeniseysk [20] Ped. Inst.					
79	Yaroslavl' Listed as Irkutsk [10]					
80	Nal'chik (Univ., Kab. Balk. ASSR)	(V)43°29.'5	43°36.'1	507	[1]	
81	Gomel'					
82	Byurakan (Obs. Arm SSR)	(V)40°19'56"	44°15'55"	1480	[1]	
83	Tartu (Sat. Obs. Sta.) (See Station No. 51)	(V)58°22'47."16	26°43'17."7	67	[1]	

Table 1 (continued)

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.		Equipment
84 (1084)	Riga Astro. observ., Lat. Univ. (See Station No. 40)	(P)56°57'08."3	24°07'01."26	39 [1]	
	Listed as Sta. at Riga State Univ.	(P)56°57'07"	1h36m28.s11 E	39 [3, text, p. 15]	NAFA 3c/25 [3, text, p. 15]; TAFO-AL-75 [24, p. 25-26]; AFU-75 [29, p. 10]; FAS [38, p. 24]; Marek camera [38, p. 24]; Laser-ranging equipment [33] for use on Antarctic-Arctic project, installed with help of specialists [45].
	Listed as Sta. at Latvian State Univ.	(P)56°57'08"	1h36m28.s08 E	39.2 [2, text, p. 14]	NAFA 3c/25-C [28, p. 5-10]
		(P)56°56'55.0	24°03'37."8	8.0 [4, p. 64]	
		(P)56°57'	24°07'	- [29, p. 21]	
85 (1085)	Birsk				
86	Blagoveshchensk (Lat. Sta.)				
87	Yaroslavl'				
88	Yakutsk				
89	?				
90	?				

Table 1 continued

Sta. No.	Station Name (Affiliation)	Station Coordinates Lat.	Long.	Equipment
91(1091)	Tobol'sk Ped. Inst.	$58^{o}02'$	$4^{h}33^{m}$ [23, p. 28]	AT-1 [23, p. 26-29]
92(1092)	Kirovsk Ped. Inst.			AT-1, TZK [25, p. 32-35]
1093	Kalingrad			
1094				
1095	Kustanay			
?	Yudino [18, p. 6]			

Key to abbreviations and symbols used in Table 1.

Station numbers:

First number - 1, 2, 3, etc. - number originally assigned to USSR stations by the Astronomical Council, Academy of Sciences.

Second number - (1001, 1002, 1003, etc.) - number assigned on a world-wide basis through COSPAR agreement.

Station coordinates:

Preceded by (V) = visual observation station

Preceded by (P) = photographic observation station

Followed by [ ] = reference to literature source of information.

Station name, followed by organizational affiliation:

Ped. Inst. = pedagogic institute

Univ. = university

Sat. obs. sta. = satellite observation station

Astron. Observ. = astronomic observatory

Lat. Sta. = latitude station

Station equipment:

a. Telescopes: AT-1, AST = astronomic telescopes
TZK = binocular telescope
AZT = reflector telescope
Lun-3 = refractor telescope
Maksutov meniscus telescope

b. Theodolites: ShT (pilot balloon theodolite)
OT-1 (geodetic theodolite)

c. **Cameras:** "small cameras" = "Fed", "Kiev", "Zorkiy", "Zenit-C", "Leningrad", "Smena-4", "Turist"; "Telemar", etc. (denoted by superscript[1] in tables).

KPP = camera with a moving film
NAFA-21
NAFA-3c/25
NAFA-3c/50
NAFA-3c/25-C

(NAFA-21 to NAFA-3c/25-C: night aerial cameras)

SBG (German tracking camera)
UF ISZ-25
AFA-MK
FAS
AFA-MK
AFU-75
VAU
TAFO-AL-75

USSR reporting of precise positions of satellite observation cameras

The only instances encountered to date in the recent open-source Soviet literature (i.e., published between 1958 and the present), in which the precise positions of satellite observation cameras are given, are reported in papers by G. V. Panova, T. Ye. Syshchenko, B. A. Firago and D. Ye. Shchegolev, entitled "Observations of the second artificial earth satellite (1957 β) at station no. 039 (Pulkovo)", Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 6, 1959, 1-5; in a paper by Syshchenko, Firago and Shchegolev entitled "The position of satellite-3 (1958 δ) from photographic observations at Pulkovo", Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 14, 1960, 17-18; and in a third paper by Panova, Syshchenko, Firago and Shchegolev, "The position of the 1958 δ_1 satellite from photographic observatories at Pulkovo, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 10, 1959, 19-23.

At the time the first paper was written, two cameras were used at the Pulkovo Observatory to obtain negatives of satellite passes:

1) a standard azimuthally-mounted NAFA-3c/25 camera, designated as the NAFA-3c/25-C, and

2) an equatorially-mounted NAFA-3c/25 camera, equipped with a clock mechanism.

The geographic (geodetic) coordinates of the camera stations are given as follows:

For (1), $B = +59^{\circ}46'13''.6$, $\mathcal{L} = -2^{h}01^{m}18^{s}.81$, $H = 76$ m above sea level

For (2), $B = +59^{\circ}46'13''.7$, $\mathcal{L} = -2^{h}01^{m}18^{s}.80$, $H = 76$ m above sea level

The paper further states that the geodetic closures of these positions were made to the center of the round hall of the Pulkovo Observatory, whose coordinates are the initial geodetic datum for the USSR triangulation on the Krasovskiy ellipsoid, here given as

$$B_0 = +59^{\circ}46'18''.55, \quad \mathcal{L}_0 = -2^{h}01^{m}18^{s}.806.$$

The second paper presents the results obtained in using the standard azimuthal camera ($F = 253.5$ mm) at Pulkovo to take 26 photographs during 21 passes of the $1958\,\delta_2$ satellite. The positions given in this paper for this camera (no. (1) in the earlier paper) are as follows:

$B = +59^{\circ}46'13''.62 \pm 0.005$; $\mathcal{L} = -30^{\circ}19'42''.08 \pm 0.01$; $H = +76^{m}.5 \pm 0.3$, $h = 0^{m}.0 \pm 0.$

$\varphi = +59^{\circ}46'13''.78 \pm 0.005$; $\lambda = -30^{\circ}19'38''.54 \pm 0.01$.

The third paper gives the following positions for A (azimuthally-mounted NAFA camera) and E (equatorially-mounted NAFA camera), where B, $\mathcal{L}$ = geodetic coordinates, φ, λ = astronomic coordinates, H = absolute elevation above sea level, h = relative elevation of the geoid above the ellipsoid:

A = $B = +59^{\circ}46'13''.62$, $\mathcal{L} = -30^{\circ}19'42''.07$, $H = +76.5$ m, $h = 0.0$ m, $\varphi = +59^{\circ}46'13''.78$,
$\lambda = -30^{\circ}19'38''.53$;

E = $B = +59^{\circ}46'13''.7$, $\mathcal{L} = -30^{\circ}19'42''.0$, $H = +76$ m, $h = 0.0$ m, $\varphi = +59^{\circ}46'13''.9$,
$\lambda = -30^{\circ}19'38''.5$.

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* BSON = Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli.

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44. Referativnyy zhurnal. Issledovaniye kosmicheskogo prostranstva, no. 8, 1973, ref. no. 8.62.240.

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47. Shcheglov, V. P. 50 years of astronomy in Uzbekistan. Priroda, no. 12, 1972, 89-93.

48. Idlis, G. M. Astronomy in the Kazakh SSR. Zemlya i vselennaya, no. 5, 1972, 54-59.

49. Französische Laseranlage in Uzhgorod (Ukraine) installiert. Feingerätetechnik, v. 21, no. 9, 1972, p. 431.

PART III

MAJOR USSR SPACE TRIANGULATION NETWORKS

Information contained in the open literature on Soviet satellite triangulation networks was selected for inclusion in this section of the report on the basis of the following considerations:

1. Availability in the U.S.A. of published data;

2. Adequacy of these data in illustrating the evolution and status of Soviet geodetic science and technology as applicable to the development of satellite geodesy and geodetic laser technology; and

3. Contributions to Soviet geodesy resulting from Soviet participation in international satellite geodesy projects.

One of the most frequently asked questions about Soviet satellite geodesy, or more precisely, all aspects of their geodesy, is "to what extent does the Soviet literature provide factual observational data that is adequate for non-Soviet scientists to verify results published in the Soviet Union?" U. S. geodesists and geodetic astronomers have been unanimous in the opinion that even with the relatively recent international cooperative agreements, adequate data have never been released to the scientific communities of western nations.

In the interest of verifying the validity of this opinion as applied to Soviet geodetic satellite networks and projects, an attempt has been made to collect all factual Soviet data published on their photographic observations of ECHO-1 (1961 and 1963). These programs were selected because these observations were the oldest (maximum time available for reductions, computer calculations, evaluations and publication) and they were the least "sensitive". Further, as so often has been the case, the tendency has been for the publication of greater amounts of information during the "first-flush of success" period. Sources, which were found to be available and which contained data on these ECHO-1 observations, are listed in Appendix A and Appendix B. As anticipated, these data would not be adequate for verification of the published results.

A. USSR Satellite Triangulation Projects Involving the Use of NAFA-3c/25 Cameras.

1. Quasisynchronous Photographic Observations. 1961 Observations of Echo-I.

The first extensive space triangulation project carried out by the Soviet Union was initiated in 1961. The purpose of this investigation was to determine the feasibility and reliability of using quasisynchronous photographic observations of a satellite to determine the unknown coordinates of one observing station when those of other stations are known.

In April-May 1961, over a period of five orbits, the ECHO-I satellite (1960_ι) was photographed at the Pulkovo, Khar'kov, Tashkent and Nikolayev stations, using NAFA-3c/25 cameras (F = 25 cm, d = 10 cm, field of view = 30° x 50°). Standard time was registered with special crystal chronographs, accurate within the ± 2 to ± 5 msec range. 34 film negatives were obtained. In processing the photographs, the coordinates of the Khar'kov station were assumed to be unknown.

The results obtained in this study have been reported by several investigators, as follows:

a. I. D. Zhongolovich, in a major paper presented at the Fourth Congress of the All-Union Astronomic-Geodetic Society, held at Riga in October, 1965 (published in 1970) [1, p. 94], discusses the basic principles of space triangulation, the establishment of base lines for space triangulation purposes and the theory of making laser measurements of distances to AES. He reports that the "Khar'kov coordinates were obtained with errors of 67, 86 and 70 m".

b. V. M. Amelin, in a paper presenting a detailed analysis of several methods of reducing synchronous photographic observations of satellites [2], uses the 1961 ECHO-I data from the same four stations (Pulkovo, Khar'kov, Tashkent, Nikolayev) as the basis for his calculations, i.e., to calculate the topocentric equatorial coordinates of the satellite. Amelin deals with two problems, the first involving the determination of the space rectangular coordinates(x_c, y_c, z_c) of the satellite and the second, determination of the coordinates of a station whose coordinates are unknown. He further states that his "results are not significant in terms of production procedures" and that "the sole purpose of the study was to develop processing methods and to throw light on the possible accuracies of these methods," (p. 3). Amelin also notes that he assumed that the coordinates of the control stations were in a single system and that for purposes of his study, the astronomic coordinates used were those listed in the COSPAR Information Bulletin, no. 10, 1962, Part I. As was the case in the 1961 experiment, the coordinates of the Pulkovo, Nikolayev and Tashkent stations, however, were assumed to be geodetic coordinates in a system of a single reference ellipsoid.

Amelin concludes that the results of his various numerical calculation methods show that the rectangular coordinates (ξ, η, ϑ) of Khar'kov could be determined with errors of the order of 100-130 m. He also notes that these errors were affected by: 1) the use of astronomic rather than geodetic coordinates, 2) the NAFA-3c/35 camera permitted determination of directions to the satellite with an accuracy of 3"-4", and 3) that the accuracy with which the moments of observation were registered was inadequate to achieve true synchronization of observations. He anticipates that if observational accuracy is improved and if geodetic coordinates in a system of a single reference ellipsoid are used for the control stations, the method of synchronous observations will make possible the determination of the coordinates of an unknown station with an error of the order of 30-50 m.

c. Using the same materials that Amelin used in (b) above, G. V. Panova and D. Ye. Shchegolev [3] applied analytical geometry formulas in computing satellite positions and to determine the coordinates of an unknown station. In this solution, the rectangular space coordinates (x, y, z) of the unknown station were obtained with errors of ± 67 m, ± 86 m, and ± 70 m, respectively.

Literature sources, containing tabulated observational data (date of observation, time of observation (U. T.) and the topocentric equatorial coordinates reduced to the 1950.0 epoch), calculated from NAFA-3c/25 photographic observations of ECHO-I during the April-May period of synchronous observations at three of the four stations (i.e., except for Nikolayev), are listed in Appendix A.

2. Synchronous Photographic Observations.

a. 1963 Observations of ECHO-I.

Impetus for the execution of a more extensive and fully synchronous photographic observational program was generated by a resolution passed at the first conference of the Commission for Multilateral Cooperation Between the Academies of Sciences of the Socialist Countries, held in November 1962, attended by representatives from the German Democratic Republic, Poland, Czechoslovakia, Rumania and the USSR [4]. The resolution called for synchronous observations to be made with NAFA-3c/25 cameras of ECHO-I during the 22 May - 29 June period over an east-west distance of about 10,000 km, extending from a group of observation stations located in eastern Europe and western USSR, across Central Asia and Siberia to a second group of ("expeditionary") stations in the Soviet Far East. The western group of stations included Poznan (Poland), Potsdam (German Democratic Republic), Prague (Czechoslovakia), Riga (Latvia), Uzhorod, Nikolayev, Zvenigorod (USSR), and Bucharest (Rumania). The eastern "expeditionary stations" included Blagoveshchensk, Vladivostok and Petropavlosk (Kamchatka) on the mainland, and a station designated as Yuzhno-Kuril'sk in the Kurile Islands. Stations intermediate between these two groups of stations generally are not identified, Alma-Ata being the only one mentioned in the literature. For the most part, the distances between stations did not exceed 3,000 km, but the Alma-Ata—Yuzhno-Kuril'sk distance was more than 5,000 km. The actual observation period began on 22 May and ended on 20 June 1973, with five observation sessions being scheduled for each day.

During the June-August period, the various stations submitted to D. Ye. Shchegolev (Pulkovo Observatory), coordinator of the project, the photographs and data required to select, from the total number of negatives, those which could be assembled into "synchronous groupings". More than 1000 negatives were selected for subsequent processing and analysis. The following figures (a, and b) show the connections for which there were more than ten synchronous negatives per triangulation side.

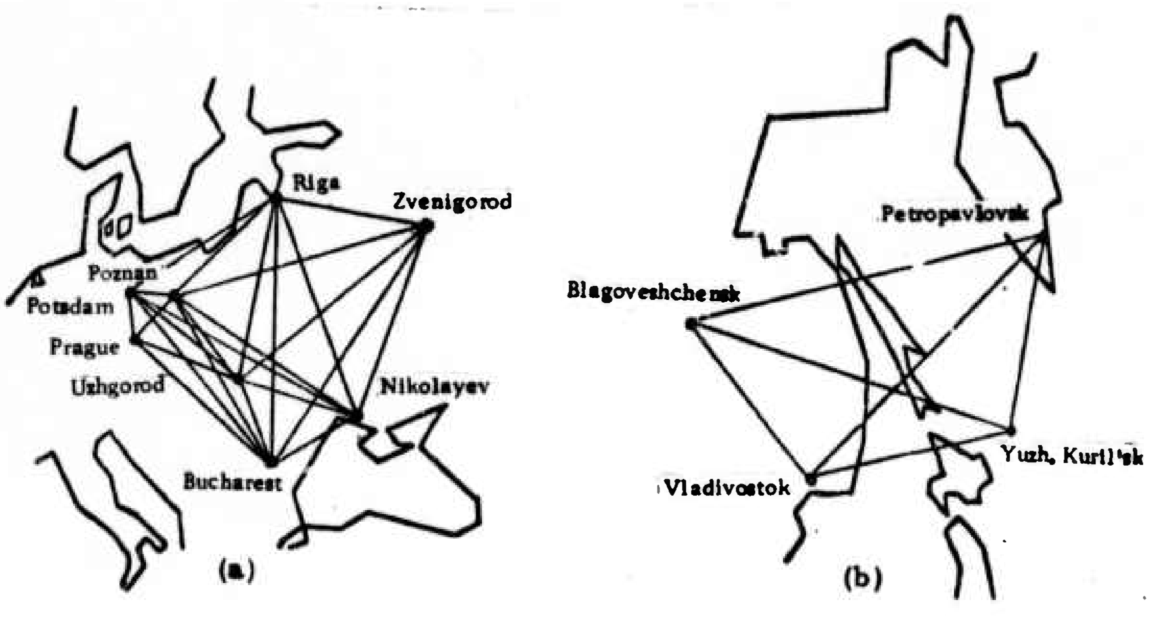

Fig. 1. Station networks for 1963 observations of ECHO-I.

The results of this project are reported by various investigators as follows:

a. I. D. Zhongolovich [1, p. 94] states that the error in determining individual directions to the satellites did not exceed ± 4", the error in time determination did not exceed ± 0.005 sec, and that of carrying forward coordinates was ± 100 m on the average.

b. Amelin, V. M.*, in a 1967 paper entitled, "Determination of station coordinates from synchronous observations of ECHO-I (1963 session)" [5], analyzes the results of a comparison of various methods of determining the coordinates of stations on the earth's surface from synchronous observations of satellites. The data used as numerical examples were selected from observations which had been made of ECHO-I in 1963 at the Riga, Nikolayev, Uzhgorod, Poznan and Zvenigorod stations. He reports the following results: With the equipment and procedures used, the topocentric coordinates of the satellite could be determined with a precision of the order of 3"-4"; the rectangular coordinates of a station could be determined with a precision of the order of 40-60 m; the geodetic coordinates with a precision of the order of 1."5 - 2."0; and the elevation of the station (with optimum matching of geodetic coordinates), with a precision of 40-60 m.

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* L. P. Pellinen cites this paper as "presenting the general principles involved in distance measurements utilizing lasers to make satellite observations". Issledovaniye kosmicheskogo prostranstva, Itogi nauki, 1970, 1972, p. 30.

c. A paper by A. G. Krylov and V. A. Yurevich [6], describing the equipment and observational and computational procedures used in connection with the 1963 synchronous observations made of ECHO-I at the far eastern "expeditionary stations", reports that there were 14 clear nights at the Kurile Island station (126 negatives obtained), and 7 clear nights at the Kamchatka station, (79 negatives, of which 32 were synchronous with other stations). About one half of the 32 negatives were of good quality. Although numerical results are not presented, the authors conclude that despite unfavorable conditions and great obstacles, "successful synchronous observations are possible under 'expeditionary' conditions."

Citations to additional references, which contain tabulated observational data for the 1963 synchronous observations obtained at a few of the participating stations, are listed in Appendix B.

b. <u>The Nikolayev (U.S.S.R.)—Helwan (Egypt) space direction determination.</u> ECHO-II observatories used for intercontinental connections.

The "circle of homogeneity" method (i.e., measurement of chord direction without time registration at one station), proposed in 1964 by C. Popovici of the Bucharest Astronomic Observatory for the determination of space directions (chords) using synchronous AES observations [7], was first used in the East European countries to determine the Potsdam - Bucharest direction [7]. Later, other directions, representing Europe - USSR geodetic connections, were determined by this method: the Bucharest - Riga direction [8]*, the Riga - Poznan and the Poznan - Bucharest directions and the Bucharest - Riga - Poznan directions [9]*.

The preliminary results obtained in using the "circle of simultaneity" method to determine space directions between widely-spaced ground stations, in this case an intercontinental connection between the Nikolayev (USSR) and Helwan (Egypt) stations approximately 2000 km apart, are reported by A. Dinescu in [10], and [11].* Five pairs of photographic observations were made of ECHO-II in the spring of 1966. The negatives were reduced at the USSR Astronomic Council; the computations were made by the least squares method. The results obtained were as follows: The azimuths of the Nikolayev-Helwan direction (read from the south toward the west) $\underline{A}$ was $1^{\circ}51'55''60 \pm 6''.80$, and the zenith distance of the direction $\underline{Z}$, $98^{\circ}32'47''.93 \pm 9''.25$, Astronomic coordinates were used for the Nikolayev station.

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* Original papers not available.

3. 1966 Synchronous Observations of the PAGEOS Satellite. Europe - North Africa Connection.

The processing, coordination and publication of the results of both the 1961 quasisynchronous and the 1963 synchronous observations of ECHO-I described above were the responsibility of the USSR Astronomic Council. After reducing and analyzing the 1963 observations of ECHO-I, the Council organized several projects involving similar, but not very successful, synchronous observations of ECHO-2. These investigations were followed by a project which consisted of the establishment of an eight-station network, from which synchronous photographic observations were made in the September-November 1966 period of the PAGEOS satellite, again using the NAFA-3c/25 cameras. The specific purposes of this study were to compare the results with those obtained in the earlier ECHO-1 and ECHO-2 studies and to determine the coordinates of the Cairo (Helwan?) station [12].

The station network consisted of the Zvenigorod, Nikolayev, Sverdlovsk, Poznan, Tashkent, Irkutsk, Khabarovsk and Cairo (Helwan?) stations (Fig. 2).

Preliminary evaluations were made of 47 photographs* taken at the Cairo station and another 100 photographs taken at the USSR and the Poznan stations. About 35% of the measurements made from the photographs

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* The paper by Kovalenko et al does not specify the type of camera used. However, Pellinen, writing in Itogi nauki. Geodeziya 1965, published in 1967 [13] identifies the cameras as being NAFA-3c/25's.

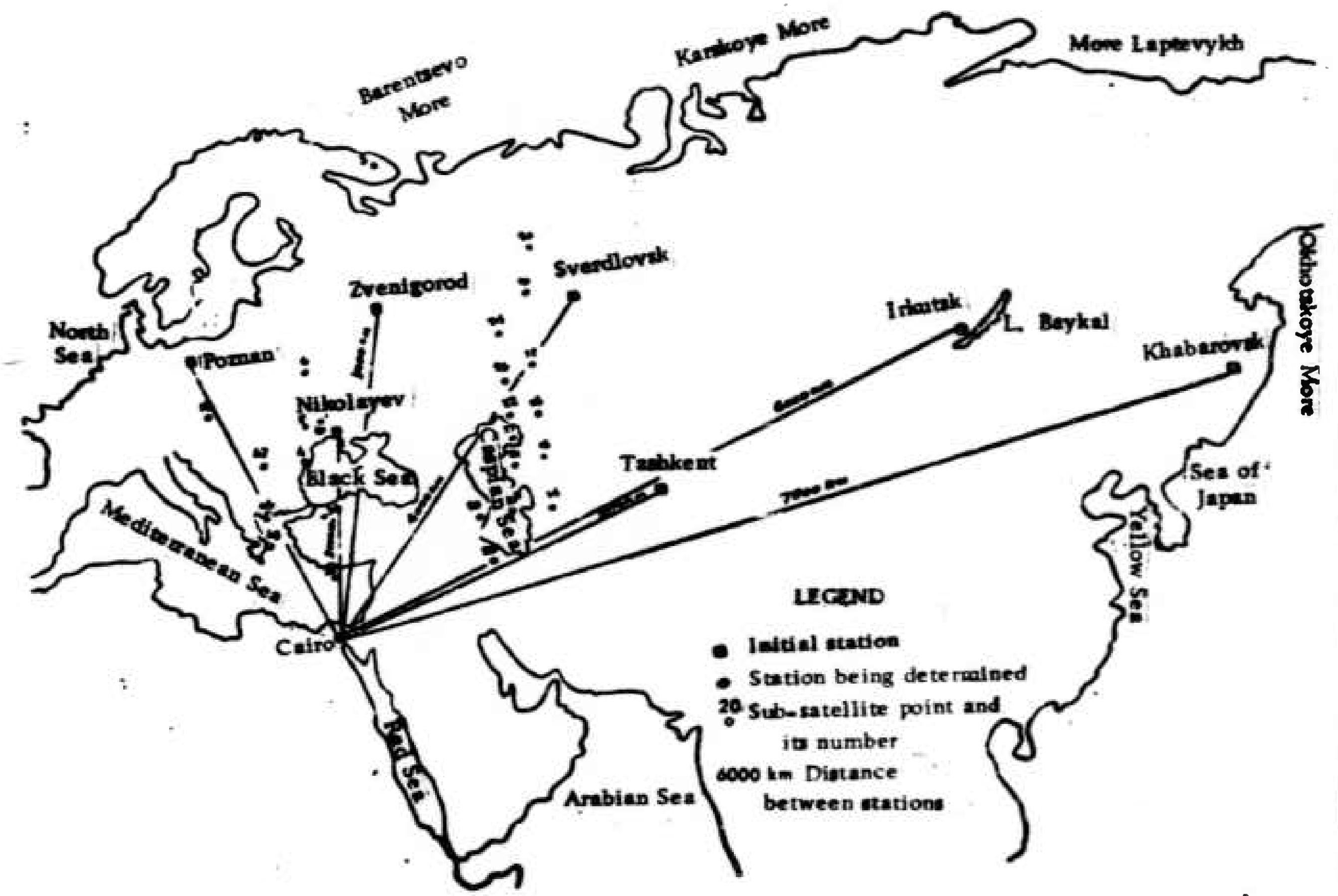

Fig. 2. **Station network for 1966 PAGEOS observations.**

were selected for the final adjustment calculations (65 synchronous photographs taken at seven of the stations, for 26 positions of the satellite). Because of the great altitude of the satellite, the maximum angle of the intersections to the satellite did not exceed 55°. Synchronous observations were obtained between stations as far apart as 7500 km. The magnitudes of the corrections to the coordinates of the satellite position did not exceed 300 m. Corrections for the Cairo coordinates were determined to be as follows:

Corrections obtained from adjustment to preliminary coordinates of the Cairo station.			Estimates, from adjustment.				
ΔX	ΔY	ΔZ	m_x	m_y	m_z	m_s	μ
+157 m	+152 m	+190 m	±79 m	±59 m	±108 m	±146 m	±4".3

where m_x, m_y, m_z are the precisions of determinations of the equatorial coordinates x, y, z of the satellite; m_s is the precision of determination of chord length, and μ is the precision of determination of the topocentric direction of the satellite.

The results of these investigations are evaluated as demonstrating that synchronous photographic observations can be made from stations located as far apart as 7500 km. The absolute value of the error in determining the position of a station (Cairo, in this case) was 148 m. However, the judgment was expressed that the geometric scheme of station disposition could have been improved by using the Irkutsk-Cairo, Tashkent-Cairo and Khabarovsk-Cairo directions. PAGEOS-type satellites are adjudged to be suitable for use in laying out a global network of space triangulation having sides of the order of 6500 km or for connecting isolated objects spaced this distance apart, but that ECHO-type satellites are preferable to PAGEOS-type satellites in laying out space triangulation networks whose sides average 3000 km in length.

The results also indicated that the tendency of the camera at Cairo to get out of focus affected the quality of the negatives obtained there and therefore also affected the final adjustment results. In the opinion of the investigators, better photographic quality and an improved station network layout would have given better adjustment results.

4. Project WESTA*.

A very interesting development (not explained in the Soviet literature) apparently occurred in the USSR space triangulation effort some time after the 1967 series of synchronous observations. This development is revealed in a paper by Minowska and Minowski entitled "Project WESTA. Processing and preliminary analysis of observational data" [14].

Examination of this paper reveals that Project WESTA was an attempt to systematize and re-reduce negatives made during the 1962-1967 period of synchronous observations of ECHO-1, ECHO-2 and PAGEOS-1 on a 13-station network in the USSR, Africa and some East European countries, (1385 negatives) and that the responsibility for coordinating, systematizing and processing these data, previously held by the USSR Astronomical Council, was being turned over to Polish scientists of the Polish Academy of Sciences [because the Astronomic Council was involved in more precise observation projects with high-precision cameras such as the Arctic-Antarctic chord?], [had too large a computer backlog?], or [were working on advanced laser techniques and instrumentation ?], etc.

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* Acronym for Eksperymentalna wschodnioeuropejska siec triangulacji satelitarnej, meaning East European Satellite Triangulation Network.

According to the list of references used in the paper, the Astronomic Council provided the Polish scientists with the following "publications" (?) (not yet located in USA libraries):

1. List of equatorial coordinates (α and δ) of the ECHO-1 and ECHO-2 satellites obtained from the 1964 [?,] synchronous observations at the Zvenigorod, Pulkovo, Riga, Uzhgorod, Nikolayev, Sofia, Baja, Poznan, Bucharest and Prague stations, published by the Astrosovet (USSR Astronomic Council);

2. List of equatorial coordinates of ECHO-2 obtained from synchronous observations in the spring of 1966 at the Cairo, Nikolayev and Bucharest stations, published by the Astrosovet, 1967;

3. List of equatorial coordinates of PAGEOS obtained from observations in the autumn of 1966 at the Baja, Zvenigorod, Cairo, Nikolayev, and Poznan stations, published by the Astrosovet, 1967;

4. List of equatorial topocentric coordinates (α and δ) of PAGEOS, published by the Astrosovet, 1968;

5. List of equatorial topocentric coordinates of PAGEOS obtained from synchronous observations in the autumn of 1966 at the Baja, Zvenigorod, Cairo, Nikolayev, Pulkovo, Riga and Uzhgorod stations, published by the Astrosovet, 1969;

6. List of equatorial coordinates of PAGEOS obtained from synchronous observations in the spring of 1967 at the Baja, Bamako, Zvenigorod, Nikolayev and Riga stations, published by the Astrosovet, 1969;

7. List of equatorial topocentric coordinates of PAGEOS obtained from synchronous observations in the spring of 1967 at the Cairo, Riga, Baja, Zvenigorod and Bamako stations (Astrosovet, 1970); and

8. Tables of the values of the topocentric equatorial coordinates of ECHO-1 positions (Astrosovet 1964).

The authors describe the results of previous attempts at preliminary establishment of a network using these data as giving "a geometric network of observation stations connected by synchronous observations [some were nonsynchronous], which had been made and reduced by several methods, with satellite coordinates having been calculated by various methods and the photographs taken with 'inferior-quality' cameras (NAFA-3c/25 except at Poznan where the PO-1 camera (F = 360 m) was used"). The paper also states that observations made after the spring of

1967 at the network stations [presumably still being coordinated by the Astronomic Council] have not been included in the Polish reprocessing of data [because after 1967, NAFA 3c/25 cameras were replaced by AFU-75 or other precision cameras?].

The WESTA network is an extension of the USSR-coordinated network of stations making observations in 1963 of ECHO-1 and ECHO-2 (the western portion of the trans-USSR network, described by Shchegolov in [4], reported in the first part of this section); its layout scheme is given in Fig. 3, below.

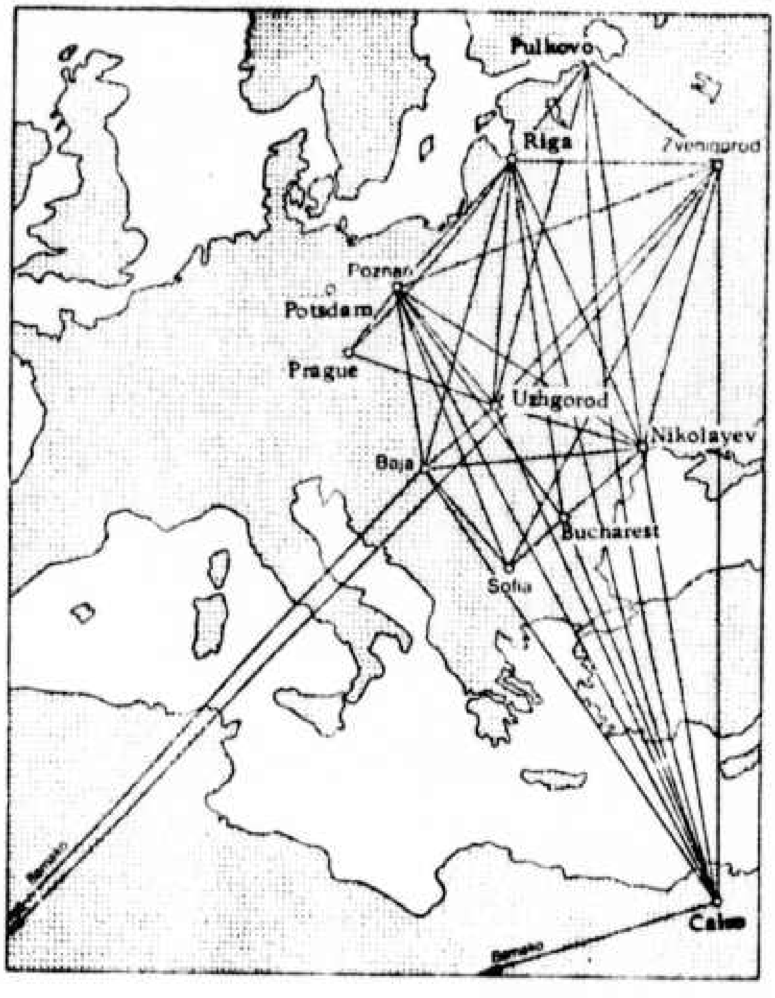

Fig. 3. Station layout for Project WESTA.

Comparison of the two networks shows that the following stations in the WESTA network were added to the 1963 network shown in Shchegolev's paper: Cairo (Helwan), Egypt, and Bamako (Mali Republic) - for connections between the USSR and Africa; Pulkovo (USSR), and Baja (Hungary) and Sofiya (Bulgaria) - for additional connections between the East European countries and the USSR.

The geographic coordinates, elevations and the COSPAR-assigned numbers of each of the 13 stations in the WESTA network are given in the following table.

Sta. no. in COSPAR list	Station name	Geographic coordinates		H w(m)
		φ	λ	
1154	Poznań	52°24'00,0"	16°52'30,0"	80,0
1072	Zvenigorod	55°41'37,7"	36°46'34,0"	173,2
1077	Nikolayev	46°58'20,0"	31°58'22,2"	51,8
1901	Cairo	29°51'30,0"	31°19'30,0"	10,0
1039	Pulkovo	59°46'13,7"	30°19'38,5"	76,5
1084	Riga	56°56'55,0"	24°03'37,8"	8,0
1055	Uzhgorod	48°38'04,6"	22°17'57,9"	189,2
1113	Baja	46°10'52,0"	18°57'35,0"	101,0
1145	Prague	50°04'56,0"	14°23'58,0"	327,0
1131	Bucarest	44°24'50,4"	25°05'47,7"	86,0
1181	Potsdam	52°22'55,2"	13°04'01,8"	108,0
1161	Sofia	42°41'02,0"	23°20'50,0"	572,0
3127	Bamako	12°38'13,0"	351°58'23,0"	333,0

Table 2. Positional data for WESTA network stations.

Here, it is interesting to note that in some cases the USSR station coordinates differ somewhat from those given in USSR publications (see Table 1). In addition, the authors point out that in determining the sides of the space triangulation, the Potsdam station was not connected to the rest of the network stations and that data obtained at Potsdam would not be used in making the overall final adjustment of the WESTA network. Finally, the authors state that "after 1963, the position of the Zvenigorod station was changed" and that "they (the authors) do not know the former coordinates".

Not only were the number of observing stations increased, but the observation sessions were also extended to include the following periods of observations of the ECHO-1 and ECHO-2 and PAGEOS-A satellites:

1) Autumn - spring of 1962-1963 (20 Sept. - 26 Sept. and 28 May - 28 June (i.e., approximately the same period previously reported by Shchegolev) observing ECHO-1 (256 negatives obtained at seven stations);

2) Autumn of 1964 (5 Oct. - 2 Nov.), observing ECHO-1 and ECHO-2 (103 negatives obtained at 10 stations);

3) Spring of 1965 (25 April - 14 May), observing ECHO-1 and ECHO-2 (64 negatives obtained at 8 stations);

4) Spring of 1966 (23 March - 25 May), observing ECHO-2 (21 negatives at 3 stations);

5) Autumn of 1966 (5 Sept. - 30 Oct.), observing PAGEOS A (813 negatives obtained at 8 stations); and

6) Spring 1967 (23 Mar. - 20 April), observing PAGEOS A (132 negatives obtained at 6 stations).

The observational data were processed with a GIER computer (operates in the FRIEDEN system) and were transferred to punched tapes. Since the WESTA network is based on synchronous observations, the data were paired for each of the connecting lines, with each observation assigned a number (1-748) in accordance with the "WESTA network catalog", which is "available on punched tapes" and "all data are kept at the Zaklad* of Planetary Geodesy, Institute of Geophysics, Polish Academy of Sciences", according to the authors. The tapes contain the following information: catalog number; date; exact moment of observation (in hours, minutes, seconds); right ascension α and δ (in degrees, minutes and seconds); mean error of direction to the satellite (in seconds of arc). The original data for α and δ were converted with an accuracy of $\pm 10^{-9}$.

* Translated as "Establishment" or "Institute".

The methods used in processing the observations are given in considerable detail, both descriptive and graphic, and this paper represents a very good example of the contrast between the data publication policies of the USSR and those of the East European countries. Another interesting feature of the Polish analysis is the fact that in converting the station coordinates (listed in Table 1) to the rectangular coordinates (XYZ), the SAO ellipsoid [not the USSR Krasovskiy triaxial ellipsoid] was used.

Examination and evaluation of the observational data indicated that the absolute directions of 50 of the lines connecting the network stations could be determined (Table 3), but 180 of the total observations of lines had to be discarded because various observational errors were discovered.

The preliminary analysis also indicated that:

1. Station coordinates were known with a precision better than ±1'.

2. Time signal registrations were precise to $+0^s.002$ - $0^s.003$. Sample calculations made in adjusting lines indicated that the anticipated errors in line determinations were < 19 and 170 > m and that the mean error of a determined line, taken as the mean error of 47 lines, was ± 74 m.

Poz	Z64	Nik	Cairo	Pulk	Riga	Uzh	Baja	Pra	Buch	Pot	Sof	Bam	Z63	Station name
1	25	25	42	1	27	10	4	11	12	0	3	0	3	Poznan
	28	8	56	31	15	2	14	0	0	0	4.	7	0	Zvenigorod 1964
		86	97	3	46	31	13	2	9	2	2	2	8	Nikolayev
			62	7	58	25	14	0	3	0	0	17	0	Cairo
				1	15	7	1	0	1	0	0	0	0	Pulkovo
					27	17	19	5	9	1	0	2	5	Riga
						8	3	3	2	0	0	0	1	Uzhgorod
							9	1	2	0	5	5	0	Baja
								0	0	0	0	0	0	Prague
									0	1	5	0	1	Bucharest
										0	0	0	0	Potsdam
											0	0	0	Sofia
												2	0	Bamako
													2	Zvenigorod 1963
163	162	248	319	66	219	101	81	22	45	4	19	33	18	Total synch. obs.
76	58	75	83	23	63	32	24	7	15	2	9	8	3	Total errors obs.
47%	36%	30%	26%	35%	29%	32%	30%	32%	33%	50%	47%	24%	17%	% of erroneous obs.

Zestawienie ogólne
materiału obserwacyjnego
sieci „WESTA" (20.09.1962-20.04.1967)

Table 3. Summary tabulation of observation materials of the WESTA network.

3. Despite certain calculation simplifications which the errors larger, the magnitude of the error $m_x = m_y = m_2 = \pm 30$ m, indicated that much greater geodetic precision was possible.

Information currently available on the second stage of processing the WESTA network data by Polish scientists indicates that Minowska and Minowski chose an English journal as the publication vehicle [15]. This part of the overall report deals mainly with the determination of the space coordinates of the WESTA network stations in a single system and the derivation of estimates of observational precisions. The paper is divided into three sections: section 1, which deals with the reduction and preliminary analyses of observational data; section 2, which describes the procedures used to determine the absolute directions of lines connecting the network stations; and section 3, the procedures used in determining the space coordinates of network stations. Preliminary and final results of the analyses are given for 47 lines, using two methods of assigning weights. The geometry of the distributions of sub-satellite points is given in sketch maps. Descriptions are also given for the method of selecting readings, the sequence of observation reduction, the methods used to smooth measurements, select directions and determine weights. Problems encountered in checking the results are described and actual processing results are given. The r.m.s. error of the unit weight (of one observation) was determined as ± 5".

B. USSR - Controlled Satellite Triangulation Projects Involving the Use of AFU-75 or Comparable Cameras.

1. "International " Europe-Africa Session of Photographic Observations of PAGEOS.

A proposal, advanced by French scientists at the meeting of Working Group I (Optical and Radio Observations of Satellites) at the Ninth Assembly of COSPAR (May 1968, Tokyo), called for a joint program of geodetic observations of the PAGEOS satellite for the purpose of determining the geodetic connections between Europe and Africa, referred to the Standard Earth system of the USA Smithsonian Astrophysical Observatory [16]. Nations agreeing to participate in the program included France, USSR, USA, Greece, Great Britain and Spain. The French Institut Geographique Nationale (IGN) was designated as the program coordinator. Fig. 4 shows the locations of stations participating in the program and Table 4, the station coordinates and types of cameras used.

Satellite observation stations in the USSR itself, stations located in the East European countries, and stations operated at least in part by USSR observers (jointly with the French in Africa), participating in the program were as follows:

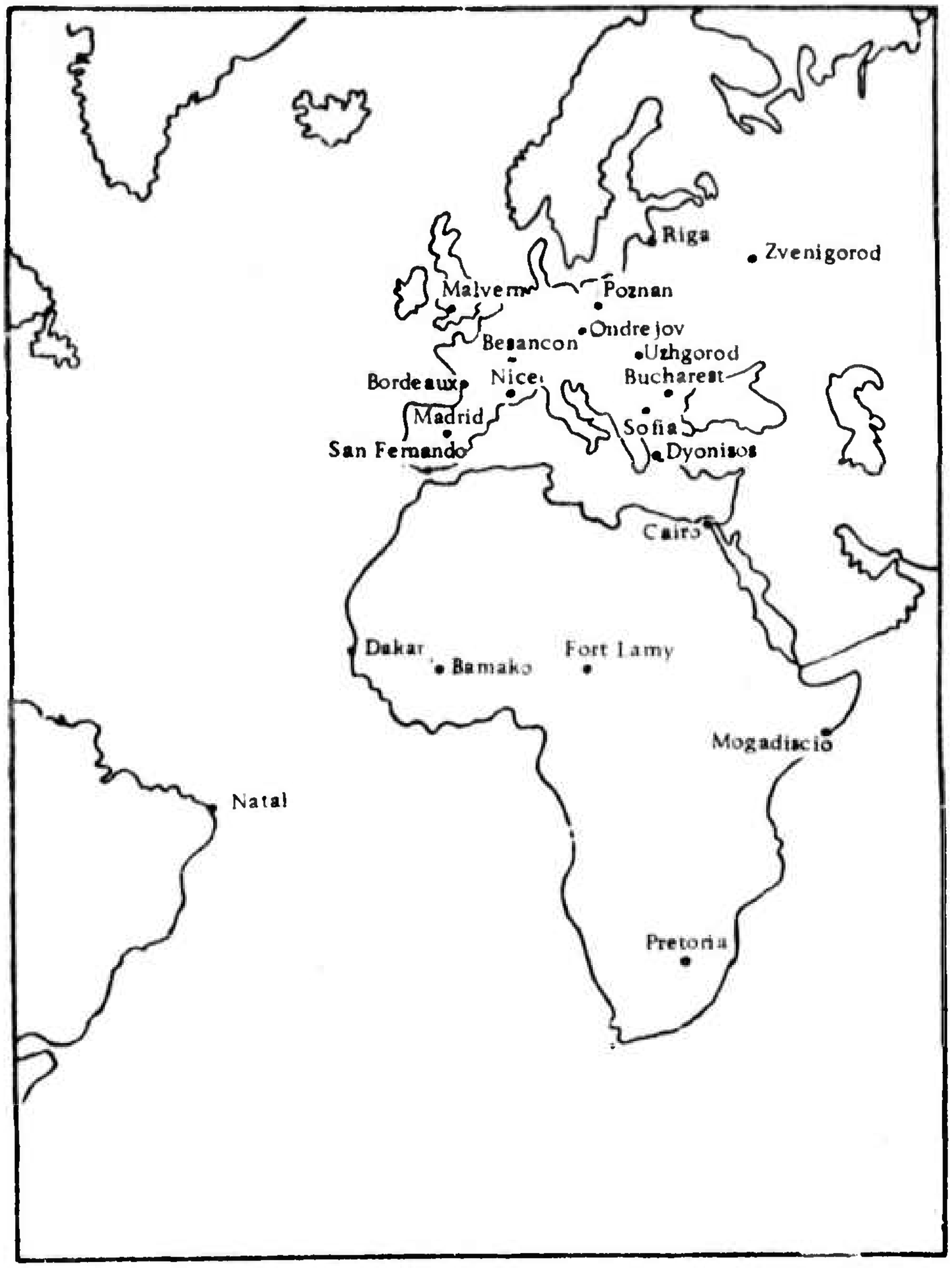

Fig. 4. Sketch map showing station disposition for the Europe - Africa program.

Table 4.

Station	Station No.	Country	Longitude λ	Latitude φ	Cameras*
Cairo	301	Egypt	$31\overset{\circ}{.}332$	$29\overset{\circ}{.}849$	AFU-75, UFISZ-25
Mogadiscio	395	Somali	$45\overset{\circ}{.}332$	$2\overset{\circ}{.}032$	UFISZ-25
Riga	198	Latvia	$24\overset{\circ}{.}116$	$58\overset{\circ}{.}952$	UFISZ-25
Zvenigorod	194	USSR	$36\overset{\circ}{.}775$	$55\overset{\circ}{.}693$	
Uzhgorod	195	USSR	$22\overset{\circ}{.}299$	$48\overset{\circ}{.}633$	
Afgoi		Somali	$45\overset{\circ}{.}121$	$2\overset{\circ}{.}144$	AFU-75
Bucharest	192	Rumania	$26\overset{\circ}{.}149$	$44\overset{\circ}{.}299$	
Ondrejov	183	Czech.	$14\overset{\circ}{.}782$	$49\overset{\circ}{.}910$	
Poznan	177	Poland	$16\overset{\circ}{.}878$	$52\overset{\circ}{.}397$	
Sofia	190	Bulgaria	$23\overset{\circ}{.}370$	$42\overset{\circ}{.}681$	
Sofia	191	Bulgaria	$27\overset{\circ}{.}919$	$43\overset{\circ}{.}199$	
Bamako		Mali			UFISZ-25

* Kovalenko's paper does not specify the cameras used at the Zvenigorod, Uzhgorod and the East European stations.

The 9 December 1968 - 28 February 1969 period was set for the observations.

The principal characteristic of the program was that the photographic program was synchronized, not in relation to time, but by the position of the observed point. The IGN was responsible for selecting satellite positions on the celestial sphere for the simultaneous observations and for providing uniform ephemeris data. A point on the satellite orbit (sub-satellite point), visible from several stations, was provided for each satellite passage used in the program.

Operations carried out in the Soviet Union were coordinated by K. K. Lapushka (Latvian State University) and N. N. Kovalenko (USSR Academy of Sciences' Astronomical Council).

In order that observations made with Soviet cameras be compatible with those made with the IGN cameras used at many of the other European and African stations, some changes had to be made in the mode of operation of the AFU-75 and UFISZ-25 cameras. Special instructions were compiled by Lapushka for making observations of PAGEOS with the AFU-75 camera, and by B. A. Firago, for the UFISZ-25 camera.

Soviet and Soviet-French stations participating in the program obtained 270 negatives, 244 of which were synchronous (Table 5).

Table 5.

Station name	Dec. 1968	Jan. 1969	Feb. 1969	Total no.
	No. of negs.	No. of negs.	No. of negs.	of negatives
Riga (USSR)	4	27	14	45
Uzhgorod (USSR)	16	30	7	53
Zvenigorod (USSR)	2	10	23	35
Cairo (UAR)	21	9	29	59
Bamako (Mali)	-	-	10	10
Mogadiscio (Somali)	1	3	-	4
Afgoi (Somali)	-	1	37	38
Total no. of negatives	44	80	120	244

In processing and reducing the PAGEOS photographs, for each second about 20 points were measured symmetrically with respect to the point of intersection of the perpendicular from the optical center to the satellite track. Up to 10 points were selected on both sides of these points in the gaps of the satellite track.

Twelve to eighteen reference stars (4-8^M) were selected on the satellite tracks, so that the overall reference star figure was as nearly circular as possible, and averaged about 50 m (4^o) in diameter.

Since identification of the reference stars selected from the SAO catalog, with preliminary measurements of their approximate spherical coordinates, was a difficult task, this operation was simplified and accelerated by the development of a computational program whereby the spherical coordinates of the selected reference stars and optical centers were calculated in terms of an initial reference star. Five to six bright stars that were easily identifiable in the catalog were selected as the initial reference stars. The spherical coordinates of the main reference stars were obtained by the Turner method. The rectangular coordinates on the photographs were measured on the "Askorekord" coordinatographs at the Riga and Zvenigorod stations and on the "Komes 3030" at Uzhgorod. At the Riga station, the equatorial coordinates of PAGEOS were determined with the BESM-2 computer at the Riga University, using the SAO 1950.0 catalog and the Turner method. In making the reductions, corrections were made for the proper motions of the reference stars, lens distortion and differential refraction. No corrections were made for annual and diurnal aberrations, time aberration and refractional parallax. Time was calculated in the IT_1 standard system.

The results were forwarded to the Institut Geographique Nationale. After all of the data had been received, the Institute transmitted the data to the participating agencies for subsequent analysis.

2. Dynamic Satellite Geodesy Project (cooperation between stations in the USSR, Mongolia, Eastern Europe and jointly operated by the USSR and France).

A paper presented by Ye. P. Aksenov and S. K. Tatevyan at the 15th Conference of the Commission for the Multilateral Cooperation of the Academies of Sciences of the Socialist Countries, held on 2-4 December 1969* at the Crimean Astrophysical Observatory entitled "Program of high-precision photographic observations of artificial earth satellites" [17] is of interest for several reasons. First, its stated purposes (determination of some of the constants of the gravitational field of the earth, and solution of dynamic problems in satellite geodesy), are very similar to those of the ISAGEX program; second, it reports the installation at several stations of the high-precision AFU-75 camera; and third, it represents the first attempt in the USSR to investigate satellite motions over extended periods of time, utilizing high-precision cameras to record data adequate for studying the nature of the forces acting on a satellite. Additional benefits expected to accrue from the study included evaluation of the usefulness of the acquired data in determining, by various dynamic and orbital methods, the coordinates of non-network stations, especially in relationship to the connection of these stations to European control networks.

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* After the 1969 COSPAR meeting in Prague.

Within the framework of the cooperating station networks, the program called for the participation of all stations equipped with AFU-75 (or comparable) long-focus satellite cameras capable of photographing satellites up to 7 stellar magnitudes, as listed in the following table.

Table 6.

	φ	λ	Camera
1. Zvenigorod (USSR)	55°42'	36°47'	AFU-75
2. Riga (USSR)	56 57	24 07	"
3. Uzhgorod (USSR)	48 38	22 18	"
4. Yuzhno-Sakhalinsk (USSR)	46 57	142 42	"
5. Cairo (Egypt)	29 52	31 20	"
6. Afgoi (Somalia)	2 09	45 07	"
7. Santiago (Cuba)	20 01	284 14	"
8. Sofia (Bulgaria)	42 41	23 21	"
9. Baja (Hungary)	46 11	18 58	"
10. Potsdam (GDR)	52 23	13 04	SBG
11. Ondrejov (Czech.)	49 55	14 47	AFU-75, SBG
12. Ulan-Bator (Mongolia)	47 52	107 03	AFU-75
13. Kerguelen Islands (France-USSR)	49 21	70 13	"

The program also envisaged the possibility that some of the west European stations and stations in the Smithsonian Astrophysical Observatory net, participating in such international programs as those of COSPAR and the IAG, also could be included.

Satellites of the GEOS-type and some of the bright passive satellites named as possible objects of observation included MIDAS-4, EXPLORER-38, GEOS-2, ECHO-1 rocket, EXPLORER-22, EXPLORER-27, DIS, DID and ANNA-1B. The authors also point out that satellites scheduled for launching during the summer of 1970 by the French (PEOLE) and by the U. S. (GEOS-C), both of which would be equipped with laser reflectors, also would be suitable for use in the program.*

Two observation sessions, each lasting four months (March-June, September-December) were scheduled for 1970. Observation methods were to be such that a 2"-3" precision in determining topocentric direction to satellites and a 0.001 sec time-registration accuracy would be assured.

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* The first official USSR pronouncement recommending that laser techniques be used in measuring distances to satellites appears to have been one of the items proposed at a seminar entitled, "Geodetic Processing of Satellite Observations," held at Tashkent from 23-25 November 1968 [18]. This meeting was organized by the Astronomic Council of the USSR Academy of Sciences, and the Astronomic Institute of the Uzbek Academy of Sciences, with the participation of the Commission for the Multilateral Cooperation of the Academies of Sciences of the Socialist Countries dealing with the problem "Scientific Research using Artificial Earth Satellites (Space Geodesy Sub-commission) in accordance with the protocol of the Conference of Experts and Representatives of the Socialist Countries on the Research for Utilization of Space for World-Wide Purposes (Moscow, 5-12 April 1967), attended by representatives from Bulgaria, Hungary, the German Democratic Republic, Poland, Rumania and the USSR.

According to the program, the Astronomic Council was responsible for supplying camera operational data, observation forms, information on presentation of observational data, data exchange, preliminary processing of data, ephemeris data, etc. to each of the participating stations at least two months prior to the first observing session. The Council was also to be responsible for the coordination of all observational data. The final reduction of observational results "is to be carried out by each of the participating countries in correspondence with its own scientific interests".

C. USSR - Controlled Satellite Triangulation Projects Involving the Use of AFU-75 or Comparable Cameras in Conjunction with Laser Observations.

1. <u>ISAGEX Program - Soviet Contributions.</u>

At the XII COSPAR meeting (Prague, 1969), the Centre National d'Etudes Spatiales (CNES) presented a proposal which called for the execution of an international satellite triangulation program. This project involved the participation of several nations in making combined laser and photographic observations of several geodetic satellites equipped with laser reflectors.

As reported by Tatevyan [19] in the Soviet literature, the program envisaged the accumulation of a large number of high-precision observations of seven satellites having different orbital parameters (inclinations of from 12° to 106°, eccentricities from 0.009 to 0.084), i.e., characteristics that are very important in solving some of the problems related to AES dynamics and in correcting the parameters of the gravitational field of the earth.

Discussions between the scientists and specialists of the several interested countries, including those from the USSR, led to a greatly expanded project plan, which was presented in May 1970 to the 13th session of COSPAR in Leningrad, became designated as the ISAGEX project, and included the execution of special synchronous satellite observations involving the joint use of laser and optical observations to determine geodetic connections between some of the stations.

The USSR proposed the inclusion of two passive satellites; no. 61028 (MIDAS-4) and no. 66058 (PAGEOS).

Observation stations of 16 nations were to participate, including those in Australia, Bulgaria, Hungary, GDR, Greece, Great Britain, USA, France, USSR, Japan, etc.

The total number of stations involved was 63, of which

15 were equipped with lasers,

3 were equipped with lasers and cameras for photographing reflected signals, 31 were equipped with high-precision tracking cameras (15 using the Baker-Nunn and 13, the AFU-75, SBG or Antares cameras),

14 were equipped with cameras which could photograph only the flashes from GEOS-2 and bright passive satellites.

The experiment was set to begin on 5 January and last until the end of June 1971.

Principal scientific purposes of the experiment:

1. Determination of the gravitational field of the earth.

Execution of a large number of high-precision laser and optical observations of various AES, made at stations evenly distributed over the surface of the earth for the purpose of determining additional linear relationships between previously calculated coefficients of the zonal and tesseral harmonics of the gravitational potential of the earth, i.e., determination of zonal harmonics to the 21st order and tesseral harmonics to the 18th order, inclusively. In addition, some of the gravitational constants could be recalculated since the scale could be reliably determined from the laser observations.

2. Geometric satellite geodesy

Since, during the experiments, 15 laser stations located in different parts of the world were to make observations simultaneously with the optical stations, the plan called for the determination of three long base lines (Fig. 5), consisting of the following stations:

a) Riga (stations in northern and eastern Europe), Wetzel, Zimmerwald, Haute-Provence, San Fernando, Dakar, Natal (Brazil).

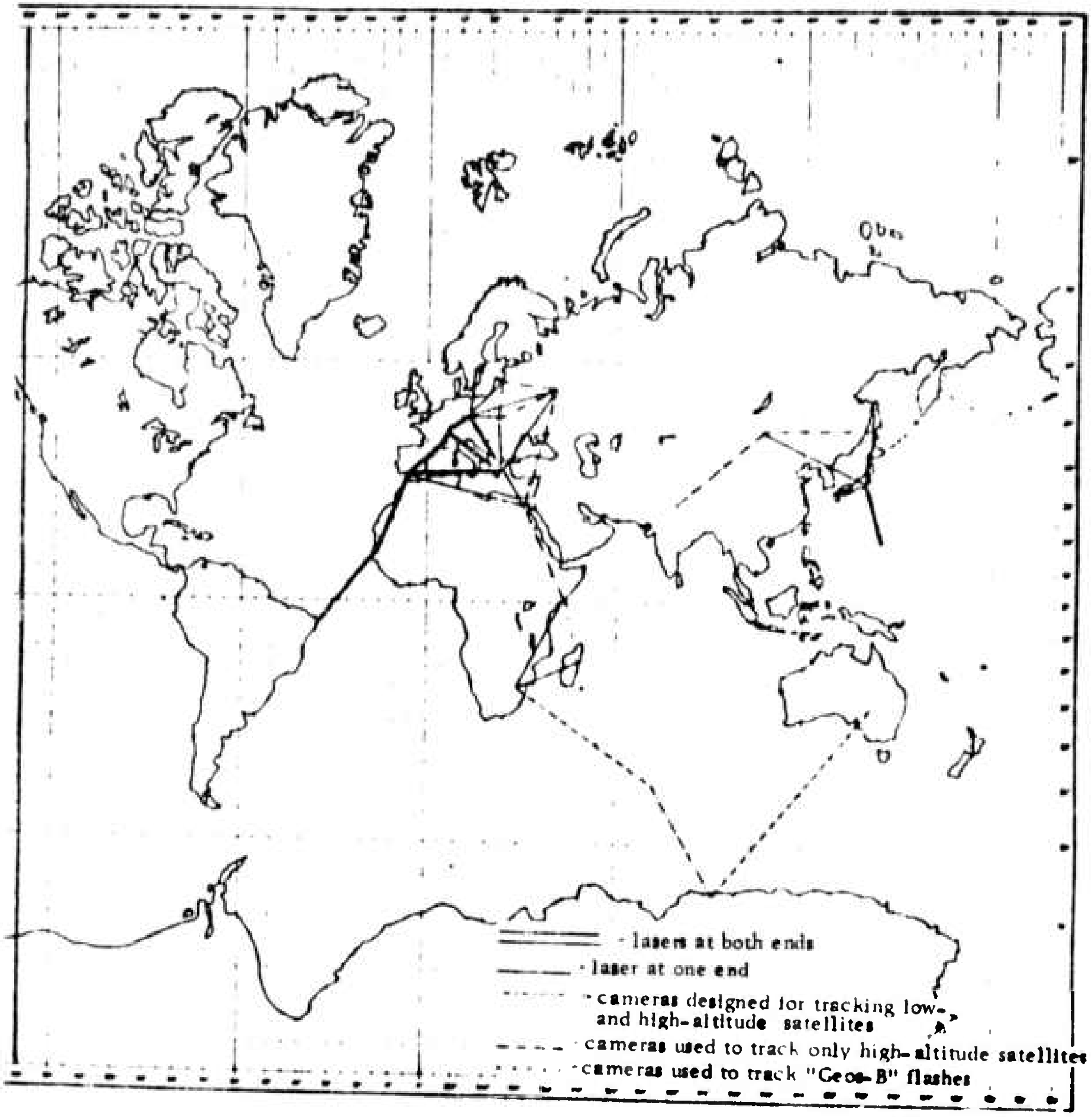

Fig. 5. Sketch map showing the disposition of base lines (ISAGEX Experiment)

b) Zvenigorod (and other stations in northern and eastern Europe), Dyonisos (Greece), Helwan, Afgoi, Olifantsfontein, Kerguelen, Mirnyy, and Woomera (Australia). The latter three stations were to be connected by observing the high-altitude satellites "MIDAS-4" and "PAGEOS".

c) Nainital (India), Ulan-Bator, Yuzhno- Sakhalinsk, Dodaira, Guam.

Geodetic connections between other stations also were to be made during the experiment, but these three lines were to receive the most attention.

For those base line sides having laser equipment at both ends, a 2-m precision in distance and a 1-sec precision in direction were considered to be possible, given a total of 20 pairs of synchronous observations (for a side length of about 1000 km) and from 20 to 100 observations for a side length of 3000-4000 km.

The scientific aspects of the experiment were to involve:

Compilation of an observation program assuring maximum scientific output,

Recommendations on methods of processing observation results;

Dissemination of information between groups of scientific researchers, etc.

Personnel designated to coordinate the experiment, included:

Kovalevskiy, J., France

Barlier, F., France

Dobaczewska, V., Poland

Gaposchkin, E. M., USA

Kosai, Y., Japan

Masevich, A. G., USSR

Veis, G., Greece

Vonbun, F. O., USA

The main coordinating center was to be the CNES; G. Bracket, Chief coordinator.

Immediate guidance of the work of the observation stations was to be implemented at five subcenters:

1. SAO, USA
2. NASA, USA
3. Ondrejov Astronomic Observatory (Czech)
4. CNES, France
5. Astronomic Council, USSR Academy of Sciences

The Astronomic Council, USSR Academy of Sciences, was to coordinate the work of the following ten stations equipped with the AFU-75 camera:*

Riga

Uzhgorod

Zvenigorod

Yuzhno-Sakhalinsk

Helwan, Egypt

Afgoi, Somali

Kerguelen (French terr.)

Mirnyy (Antarctic)

Ulan-Bator, Mongolia

During the experiment, observations made at the stations were to be forwarded to the subcenters and then to the CNES. Upon completion of the entire program, CNES was to compile a general catalog of all of the observations and present it to the Scientific Committee for discussion.

The observation results were to be distributed in accordance with the recommendations of the Scientific Committees of all of the scientific organizations and separate groups of investigators "in accordance with their scientific interests".

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* The publication, COSPAR Bulletin no. 53, 1970, p. 15, notes that the following stations equipped with AFU-75 cameras also participated: Sofia, (Bulgaria), Ondrejov (Czechoslovakia), Bucharest (Rumania), and Baja (Hungary).

Results of Soviet ISAGEX observations as reported in the Soviet scientific literature.

The available Soviet literature contains almost no specific information on the results obtained at the Soviet stations participating in the ISAGEX program. One paper, written by S. K. Tatevyan [19], states that a preliminary experiment was carried out from 15 September to 1 November 1970 to: 1) finalize the communication system between CNES, the subcenters and the stations; 2) to check the accuracy and operational status of the ephemeris service; 3) to adjust apparatus at the new stations; and 4) to determine the geodetic directions between remote stations from observations of the "MIDAS-4" and "PAGEOS" satellites, and that all of the USSR Astronomical Council's stations equipped with AFU-75 cameras participated in these observations. Ephemeris computations were made at the Institute of Theoretical Astronomy and at the Riga satellite observation station.

Tatevyan also reports that unfortunately, due to poor weather, very few observations of the faint satellites were obtained. However, he says that "this preliminary experiment made it possible to better coordinate the operational connections between the Council, the Computer Centers and the observation stations and that the results of this experiment will be discussed between all of its participants".

A second source [20] contains the following tabulated observational data, which are described as having been obtained in accordance with the ISAGEX program.

Period of observation - September 21 to October 30, 1970*;

Satellites observed - No. 68002, 64064, 67011, 65032, 65089, 67014;

USSR stations observing these satellites and the periods of observations:

Satellite	Stations	Periods of observations
No. 68002	1014 (Vologda) 1035 (Novosibirsk) 1051 (Tartu)	Sept. 21-22, 24-28; Oct. 8, 11, 27, 29.
No. 64064	1014 (Vologda (?)) 1023 (Kiev) 1027 (Krasnodar) 1035 (Novosibirsk) 1042 (Ryazan') 1051 (Tartu)	Sept. 21-28; Oct. 2, 7, 8, 10, 12.
No. 67011	1018 (Yerevan) 1052 (Tashkent)	Sept. 26-30; Oct. 1-5, 7-8, 26, 28;
No. 65032	1052 (Tashkent)	Oct. 10, 25-28.
No. 65089	1018 (Yerevan) 1027 (Krasnodar) 1042 (Ryazan') 1051 (Tartu)	Sept. 26; Oct. 3-4, 6, 11, 26, 30; Nov. 6.
No. 67014	1018 (Yerevan) 1052 (Tashkent)	Sept. 27-28; Oct. 3-6.

* Some data obtained at the Tartu station are given for November 6.

Other data tabulated: UT

α-right ascension

δ-declination

2. The Arctic - Antarctic Geodetic Vector Project

The proposal for executing the Soviet Arctic-Antarctic geodetic vector project, combining the use of high-precision photographic observations with simultaneously executed laser ranging measurements of artificial satellites, was presented by I. D. Zhongolovich (Institute of Theoretical Astronomy) at the 15th conference of the Commission for Multilateral Cooperation of the Academies of Sciences of the Socialist countries on the problem: "Scientific Research Using Artificial Earth Satellites", held on 2-4 December 1969 at the Crimean Astrophysical Observatory of the USSR Academy of Sciences [21].

In this paper, Zhongolovich briefly discusses the theory and summarizes the results already obtained in using dynamic methods of determining directions and distances to satellites, geometric methods of determining the relative positions of stations on the surface of the earth, and the determination of the direction and length of a chord connecting two stations. Chord direction and length accuracies, estimated by Zhongolovich as possible for chord segments and for the entire Arctic-Antarctic traverse, are based on data reported for the Organ Pass-Jupiter chord published in the Smithsonian Astrophysical Observatory Special Reports, nos. 200(1966) and 264(1967).

The seven-station layout (six geodetic vectors), proposed by Zhongolovich for the traverse, and the connections of each of the stations to existing triangulation stations or networks in Europe, Africa, the Arctic, Indian Ocean and Antarctica, are illustrated in the following figures. As these figures show, the proposed* stations would include Barentsburg (Spitzbergen), Zvenigorod (USSR), Cairo (Egypt), Mogadiscio (Somaliland), Reunion Island (Indian Ocean), Kerguelen Island (Indian Ocean) and Mirnyy (Antarctica). The total length of the six chords is given as 16,900 km, the average length of a chord being about 2800 km (varies from 2170 to 3390 km). The length of the subtending chord extending from Mirnyy to Barentsburg is given as about 12,400 km, i.e., almost equal to the diameter of the earth. The proposal specifically calls for the installation of geodetic lasers at a minimum of three stations (Zhongolovich suggests the Kerguelen, Mogadiscio and Zvenigorod stations).

In Zhongolovich's view, each of the geodetic vectors would have to be determined as accurately as possible, both in relation to the direction of the chord from an adequate number (> 50) of judiciously disposed synchronous planes and in relation to the length of a chord, determined from a large number (> 40) of special laser measurements of

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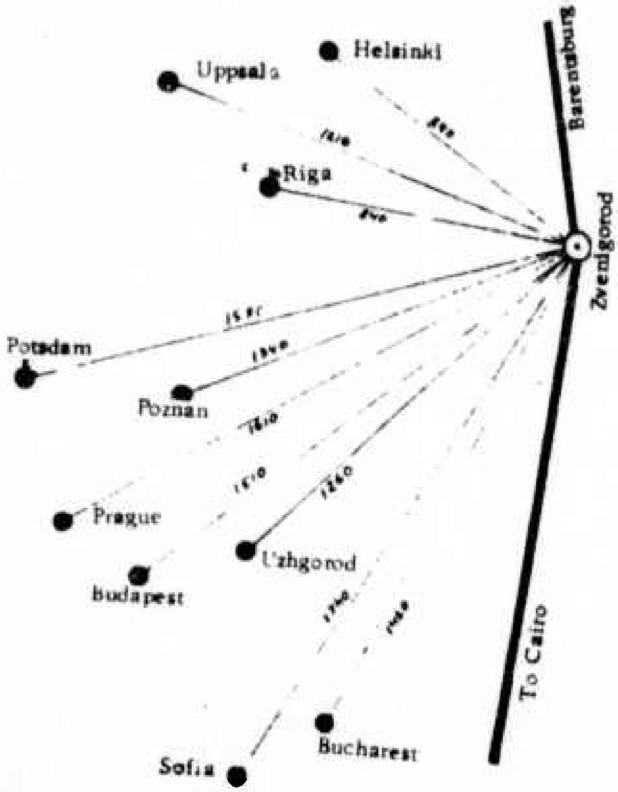
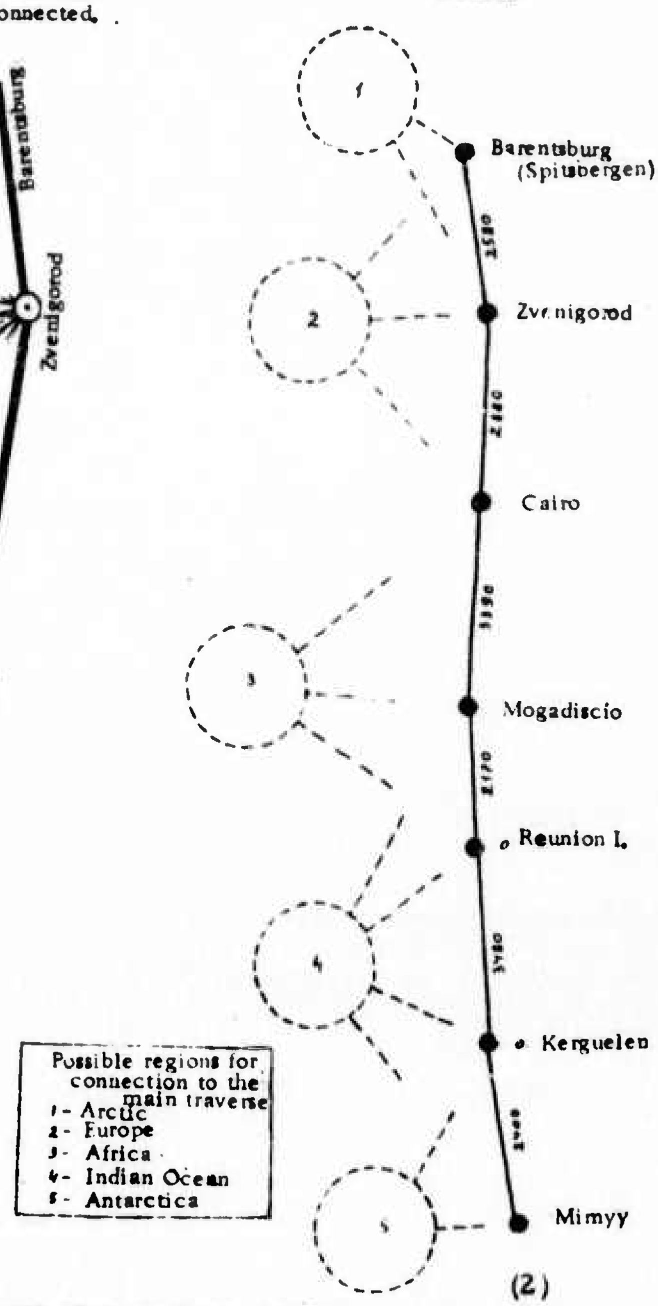
* Zhongolovich notes that future circumstances might result in changes in station selection.

Sketch showing
possible European stations to which the
main geodetic vectorial traverse can be connected.

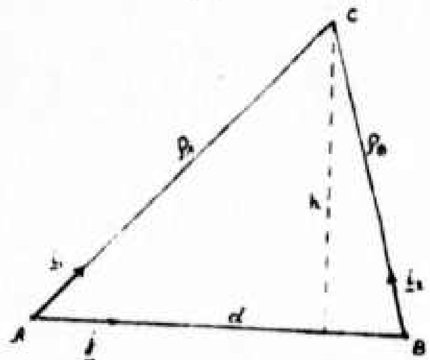


(3)

Sketch of the
Arctic-Antarctic geodetic vectorial
traverse



(2)



$s(t,d)$, $s(t_1,d_1)$, $\boxed{s(Y,N)}$, ρ_1, ρ_2

(1)

Length of all six chords - 16900 km
Length of subtending chord - 12,400 km
Anticipated precision of determinations of length of each chord $2 \cdot 10^{-6}$; length of subtending chord $1 \cdot 10^{-6}$

Fig. 6. Station layouts proposed for the Arctic-Antarctic project.

the topocentric distances to geodetic satellites equipped with corner reflectors, carried out simultaneously with measurements of directions to the satellite from the ends of the chord being determined.

Zhongolovich anticipates that the length of each chord can be determined with a precision of about 1:500,000 and that the total length of the subtending chord can be determined with a precision of about 10^{-6}.

Additional information on the details and progress of the project was given in a paper presented by Masevich, Yerpylev, Lozinskiy and Tatevyan at the 15th General Assembly of the IUGG, held in Moscow, July-August, 1971 [22]. These authors report that the geodetic vector traverses are to be laid out in two stages of operation:

Stage I - each of the constituent geodetic vectors is to be oriented from synchronous photographs of high-orbit satellites, with several dozens of synchronous pairs of satellite tracks being obtained. Here, it is assumed that sub-satellite stations are favorably positioned in respect to the chord.

Stage II - simultaneous photographic and laser tracking of the satellites is to be carried out from the terminal stations of each vector. Knowing the chord direction, each of the simultaneous photographic and laser tracking observations will make calculation of the chord length possible.

Assuming that the "present" precision [1971] of photographically determining directions to a satellite against a star background is within the limits of ±1" and that of determining the topocentric distances with laser ranging equipment is ~1 meter, Zhongolovich is quoted as estimating that a single 2,000-3,000 km vector of the chord can be measured with a precision of ±0.4" in direction and ±4 m in distance.

Stage I was initiated by the USSR Academy of Sciences in 1970 when experimental observations were made of PAGEOS and MIDAS-4 (April and May 1970). Work carried out at stations under the direction of the USSR Academy was supplemented by that executed at the French station at Nice, at Pretoria (S. Afr.), and at the station jointly operated by the Soviets and France on Kerguelen Island. Observations made at these stations in September-November 1970 are reported as having been contributed as a part of the preliminary stage of the ISAGEX project, in compliance with recommendations made by the 1970 COSPAR conference in Leningrad to the effect that the ISAGEX program during the first half of 1971 would include observations made to determine the directions of this type of geodetic vector. Having completed observations, the ISAGEX program was to be continued as an independent international geodetic program.

In conformity with the Soviet view that the Arctic-Antarctic chord project should be supplemented by laying out an equatorial chord between South America and the Far East, where the Tokyo Astronomic Observatory is working on an Eastern Asian arc, new stations are being established at Khartoum (Sudan) and Fort Lamy (L. Chad), at the intersection of the polar and equatorial traverses, and the establishment of yet another station in Latin America is under consideration.

In stage II, several scientific institutions in the Socialist countries are to cooperate internally in building laser-ranging equipment to be used in satellite measurements. This equipment is to be a "rather simple instrument of adequate precision", that "can be easily moved from one station to another", ... "will have a four-axis mount similar to that of the AFU cameras, and is to be ready for field investigations in 1972."

3. World Triangulation Project Proposed by I. D. Zhongolovich.

A paper by L. Minowska [23], entitled "Numerical analysis of world satellite triangulation network projects" numerically analyzes and compares models of the world triangulation projects proposed by Zhongolovich and by H. H. Schmid of the U. S. Coast and Geodetic Survey [at the time the proposal was made].

The Zhongolovich proposal presents a scheme for a world-wide space triangulation network, which consists of 20 plane triangles, 30 chords (sides of triangulation) and 12 stations. This scheme is derived from an inscribed icosahedron, the stations being located at the vertices of the icosahedron, and with an additional station located in the Pacific Ocean (see Fig. 7).

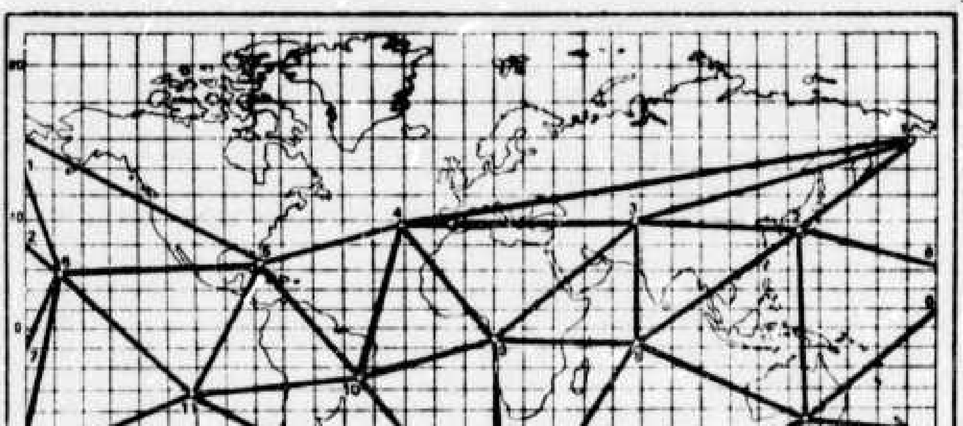


Fig. 7. Station layout for Zhongolovich's world **triangulation project.**

The geographic coordinates φ and λ and the rectangular coordinates of each of the proposed 13 stations are given in the following table.

Table 7.

Nr pktu	φ	λ	X [m]	Y [m]	Z [m]
1	+64° 51′ 08″	+178° 30′ 00″	−2 702 045	+ 70 756	+5 757 735
2	+37 58 47	+139 00 00	−3 789 428	+3 294 099	+3 920 022
3	+39 48 38	+ 68 30 00	+1 793 191	+4 552 281	+4 078 003
4	−37 48 48	+331 00 00	+4 401 481	−2 439 781	+3 905 461
5	+27 02 38	+280 00 00	+ 985 769	−5 590 572	+2 897 956
6	+22 10 54	+199 00 00	−5 581 666	−1 921 922	+2 406 899
7	+35 19 06	+139 00 00	−3 923 308	+3 410 480	−3 683 184
8	− 6 21 27	+ 72 00 00	+1 958 760	+6 028 442	− 706 237
9	− 5 15 53	+ 12 10 00	+6 208 424	+1 338 529	− 585 227
10	−20 22 27	+318 30 00	+4 476 286	−3 960 284	−2 219 638
11	−26 50 41	+251 00 00	−1 851 477	−5 377 080	−2 878 228
12	−39 48 38	+177 00 00	−1 886 024	+ 256 066	−4 078 003
13	−69 52 34	+ 15 00 00	+2 113 385	+ 566 280	−5 971 066

Zhongolovich's proposal envisages that a special geodetic satellite, orbiting at about 10,000 km, would be observed from each station and that the lengths of the triangle sides would range between 3,500 and 7,800 km. (For the purpose of the Minowska paper, laser observations are assumed).

The author's conclusions, based on several models, as applied to the Zhongolovich proposal, are of interest for several reasons. In terms of ability to determine station positions provided that direction and distance observations are determined under optimum conditions, the project is favorably evaluated. On the other hand, Minowska notes that there is no satellite of the required type available [at the time of writing] nor are there pla..s for launching one and, further, "we do not possess laser equipment of satisfactory capacity to implement such a proposal".

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2. Amelin, V. M. Experience in the reduction of synchronous AES observations. Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 39, 1964, 3-8.

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PART IV

USSR AND EAST EUROPEAN CAMERAS USED FOR SATELLITE GEODESY PURPOSES

The most recent review-type reports published in the Soviet Union, which contain information on the satellite cameras used in the USSR and the East European countries, were included in papers either published in 1970 or containing 1970 data. Papers of the first type were prepared by the well-known geodetic astronomers A. G. Masevich and A. M. Lozinskiy of the Astronomic Council, USSR Academy of Sciences [1], the English translation (?) of the original paper [8]*, and in a paper presented by A. G. Masevich, N. P. Yerpylev, A. M. Lozinskiy and S. K. Tatevyan at the 15th General Assembly of the IUGG [2] held in Moscow, July-August, 1971. A compilation prepared by L. P. Pellinen [23], summarizing and systematizing information published in 1970 in the USSR abstract journal, Referativnyy zhurnal, covering many aspects of space research (investigations of the gravitational fields and the shape of the earth, other planets and the moon from space vehicle observations), falls in the latter category.

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*. The source of this "translation" is not known, i. e., whether it was made by the Soviets or by other translators. It is also of interest to note that the two sources differ in minor details, information in the "original" sometimes being omitted from the "translation", or vice versa.

According to these and later, more detailed sources, the following cameras are presently being used by the USSR and the East European countries in carrying out various projects in satellite geodesy:

Non-Tracking Cameras

NAFA/3c/25(USSR), replaced or being replaced by

UFISZ/C, UFISZ/25, UFISZ-50(USSR)

FAS(USSR)

Poznan, Poznan-2 (Poland)

Marek (GDR)

MK-75 (USSR)

Schmidt - Väisälä (Finland)

Tracking Cameras

VAU (USSR)

AFU-75 (USSR)

SBG (GDR)

The following summary of technical information on these cameras, collected from the literature, contains no information on the SBG or Schmidt-Väisälä cameras, since detailed information is readily available in the German and Finnish literature and the cameras are assumed to be well known to American specialists. Data on the USSR NAFA-3c/25 camera, used almost universally in the USSR until 1969, are also omitted since details on this camera have been available for several years and also because Soviet reports state that these cameras have been or are being replaced by the UFISZ cameras at USSR and East European satellite observation stations. The limited amount of data presently available for the new UFISZ-type cameras, however, are presented below (Section A).

A. Non-Tracking Satellite Cameras

1. UFISZ-type cameras

Several authorities [1, 3] describe the UFISZ-type cameras built in 1959 [3], as updated, improved and partially redesigned versions of the NAFA-3c/25 cameras used so extensively at stations in the Soviet satellite observation network mostly for acquisition of ephemeris data. Several authors state that UFISZ cameras have replaced the NAFA cameras at most of the USSR and East European stations.

The technical and operational data for these cameras, reported in the literature published in the 1970-1973 period, are summarized as follows:

Masevich [1] says that the updated version of the NAFA-3c/25 is designated as the UFISZ/C but that the UFISZ-50 (d = 100 mm, f = 500 mm) is used at some USSR stations. Boyko et al [3] give the following technical characteristics of the UFISZ-25:

Lens, Uran-4;

Focal length, 25 cm;

Relative aperture, 1:25;

Shutter, jalousie-type; closed and opened by a digital printing chronograph, operated from a crystal oscillator.

The camera uses film only. Passive satellites of 4^M, moving at an angular velocity of up to 1°/sec, can be photographed. The precision with which directions to a satellite are determined is given as ±5-7".

An abstract* of a paper by K. M. Antonovich [6] describes the method used in determining the moments when satellite pictures are exposed with an UFISZ-25 camera and reports that the r.m.s. error of determining the moment of mid-exposure is ±4.6 msec. The true error, determined from photoelectric registrations, is reported as being ±2.8 msec.

The UFISZ/C is described by Masevich [1] as differing from the NAFA-3c/25 in that the jalousie-type spring-loaded shutter, which in the NAFA-3c/25 had been activated by a motor, now is activated by an electromagnet, the electric motor being used only to provide power for advancing the frames. The camera is installed on a simple and convenient stand to permit vertical and azimuthal pointings.

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* Original paper not available.

2. The FAS Camera

Lapushka and Abele (Riga University) have also designed and built a new camera (FAS) specifically for photographing active satellites. Fig. 8 is a photograph of this equipment and Fig. 9 is a generalized schematic of its optics.

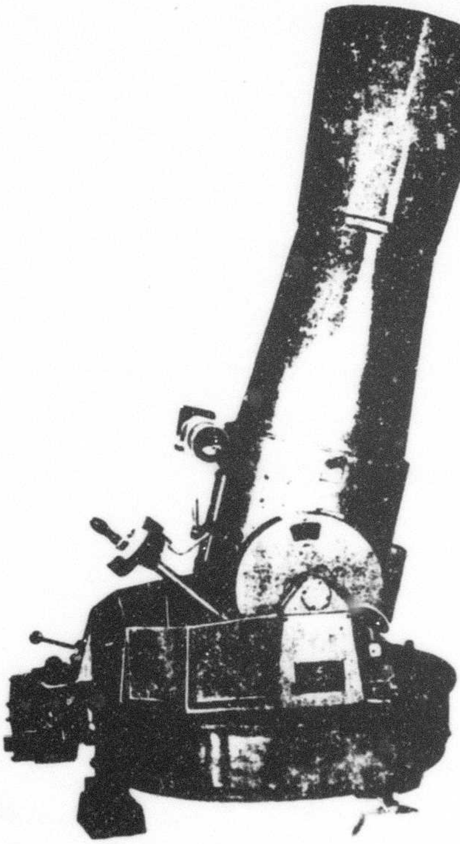

Fig. 8. The FAS camera[8].

Like the AFU-75, this camera is mounted on an equatorial platform; its operating principles are identical to that of the AFU-75, differing only in that it is structurally improved and is more stable. The camera is mounted on a biaxial platform.

The camera has a mirror-lens objective, as shown in the following schematic (Fig. 9).

D = 250 mm, D/F = 1/2

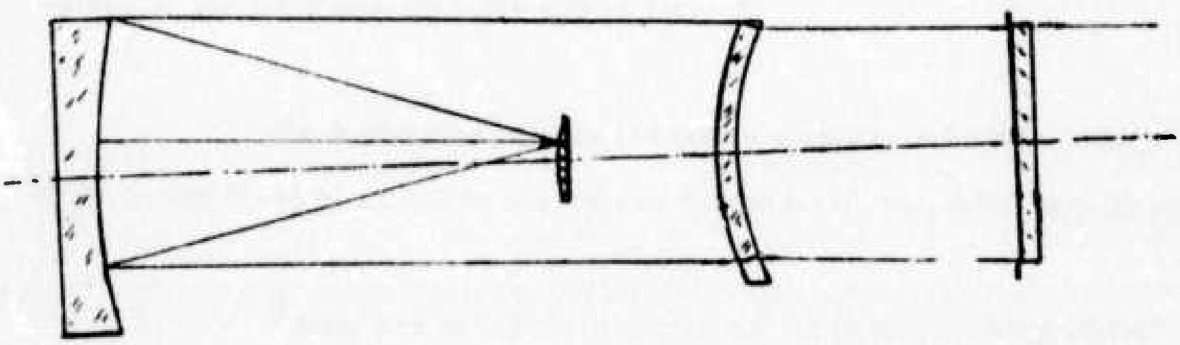

Fig. 9. Optical schematic of the FAS camera.

The main mirror is spherical and is 300 mm in diameter. The surfaces of the meniscus and mirror have common centers of curvature. The front lens is planoconvex and has a large radius of curvature. The telescope aperture is 250 mm in diameter, and its focal length is 480 mm, d/f = 1:19. The focal surface is flat.

The optical system is distinguished by the feature that all observations (except distortion) are well corrected. Achromatism ranges from 400-700 mμ. The lack of aberrational distortions and secondary spectra result in very clear star images, 20 mμ in diameter.

The photographs are taken in the prime focus on plates or film, 6.5 x 9 cm in size. The dimensions of the field of the photograph are $7^{\circ} \times 10^{\circ}$. The resolving power of the objective is 40 lines/mm in the center of the field and over the entire field.*

Each plate or film is loaded in a separate holder, which sets them in the focal plane. The plates can be replaced manually in 8-10 seconds.

There are two possible methods of photographing active satellites with this camera. In the first method the equatorial platform is operational and the star images on the photographs appear as points. The second (vertical) axis has a device for discretely moving the camera vertically by 2" of arc. This results in double star images which make satellite flash images easier to find.

In the second method the equatorial platform is engaged and the stars appear as dashed lines on the photographs. Moments of time must

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* This latter statement appears only in the English translation [8] of the original paper.

be noted for the beginning and end of each dashed line. For this purpose special contact is made with the camera shutter, and a signal from this contact is fed to the printing chronograph. This method is less precise than the first and timing instruments are required. The camera shutter is opened manually and is set from a long arm in front of the focal plane.

The servo drive of the equatorial platform is powered by a d.c. motor, whose synchronous revolutions are regulated by a balance mechanism. The motor is fed 5 volts from 1.5-volt dry cells. Checking determinations made of internal precision from the computed star positions and comparison with their catalog coordinates show deviations in results of from 1".5 to 3".0. An internal precision identical to that of the AFU-75 for different focal lengths is due to the fact that the star images taken with the FAS-3A are significantly clearer (good optics), thus reducing the errors in measuring rectangular coordinates.

By the end of June 1969, FAS cameras had been installed at the Riga, Zvenigorod, Uzhgorod, Pulkovo and Yuzhno-Sakhalinsk stations.

3. Poznan-2 Camera (Poland)

This camera, built in accordance with G. G. Hurnik's (1968) design, was first installed at Poznan and then at the Sofia and Riga stations. The camera lens is the "Telemar" (diameter, 140 mm; focus, 1000 mm), used in aerial surveys. The camera uses 13 x 18 cm plates but film also can be used. The field of view is $6^{\circ} \times 8^{\circ}$. The aperture is about 14 cm [23]. It has a device which photographs (on the edge of the plate) the declination and hour angle (right ascension) readings to one-degree accuracy, and clock dials at a reading accuracy of up to 1 min. An obturator rotates in front of the lens to mark the satellite track and to register time. The effective time for opening and closing the obturator shutter for a satellite having a brightness of PAGEOS is 8 milliseconds, and an exposure time of 24 milliseconds. A photodiode is used to register moments of time. In addition to the obturator shutter, there is a leaf-type shutter shutting off the objective from the side toward the holder. The camera is mounted on an ordinary equatorial stand (Fig. 10 on the following page).

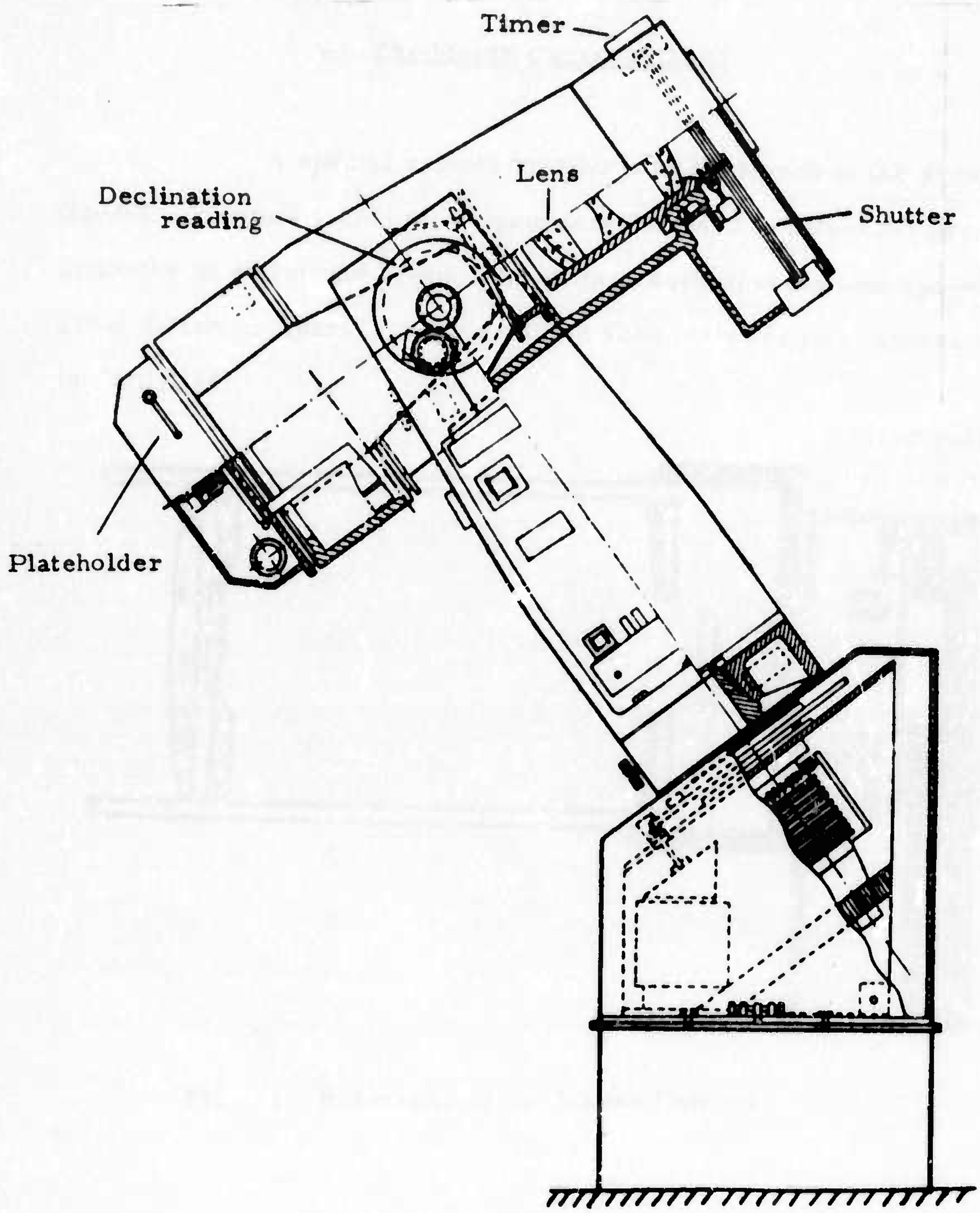

Fig. 10. Schematic of the Poznan -2 camera.

4. The Marek Camera (GDR)

A special camera was built by K. Marek at the Potsdam Geodetic Institute (GDR) for a "program designed to obtain the precise azimuths of directions between satellite observation stations spaced great distances apart". A generalized schematic for this camera is given in Fig. 11 [1].

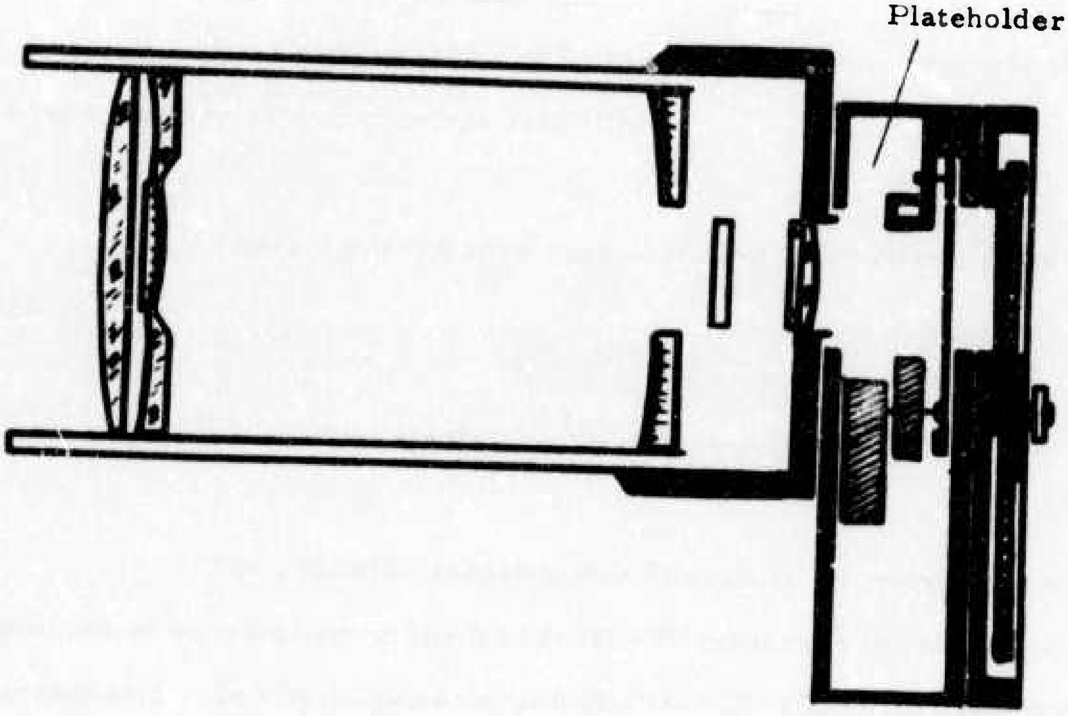

Fig. 11. Schematic of the Marek Camera.

This instrument consists of:

Telescope, 200 mm (in diam.); $f' = 964$ mm; aperture ratio = 1:5.6; field of view = $3^\circ.5 \times 4^\circ.7$;

Special equipment for time registration;*

Interchangeable holders

Guide, 110 mm in diameter

Nine photographs can be taken at 2-minute intervals during a single passage of an Echo-type satellite.

These cameras have been installed at Potsdam, Sofia and Riga.

5. The NAFA MK-75 Camera (USSR)

The available recent Soviet literature provides only a minimum of information on the NAFA MK-75 camera (Fig. 12). An abstract of a paper by Logvinenko and Dul'tsev [5] states that descriptions of camera modifications, including the redesign and manufacture of a new azimuthal mount for the MK-75 at the L'vov station, are given in a paper

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* Details are reportedly given in: "Nablyudeniya ISZ", no. 3, Berlin, 1965, 161-167 [Not available at the time this report was written].

Fig. 12. MK-75 Camera

published by the L'vov University*; the original paper, however, had not been located at the time this report was being written. Other sources of information, in the form of a photograph of the camera and the principal characteristics of the lens, are given by Fel'sman [15], by Masevich [1, 2], and by Guseva [9], who give some of the technical characteristics of the MK-75 located at the Zvenigorod station (station 1972) and mention that

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* L'vov. Universitet. Astronomicheskaya observatoriya, Tsirkulyar, no. 47, 1972, 36-40.

this camera is used "to photograph minor planets".

The following table summarizes information currently available on the technical parameters of this camera (Table 8).

	Logvinenko [5]	Fel'sman [15]	Guseva [9]	Masevich [1, 2
Lens	Uran-16			
D		20 cm	21 cm	200 mm
F	750 mm	75 cm	74 cm	750 mm
Relative aperture	1:3.5			
Field of view			$22\overset{\circ}{.}40 \times 22\overset{\circ}{.}40$	
Use	Photographs active and passive satellites for triangulation purposes		Used to photograph minor planets	
Accuracy (position of satellite)	2"			

Table 8. Technical characteristics of the NAFA MK-75 camera.

B. SOVIFT TRACKING CAMERAS

1. The VAU Tracking camera (USSR)

The VAU camera, described as being the largest satellite tracking camera in the world, was designed for making high-precision photographic observations of the positions of artificial earth satellites and remote "artificial space bodies" [1, 2]. The first VAU was installed and investigated at the Zvenigorod station in 1969 [4]. Photographs of the VAU installation and its optical schematic are given in Figs. 13, 14 and 15.

Fig. 13. Photograph of VAU installed at Gissar Observatory [31].

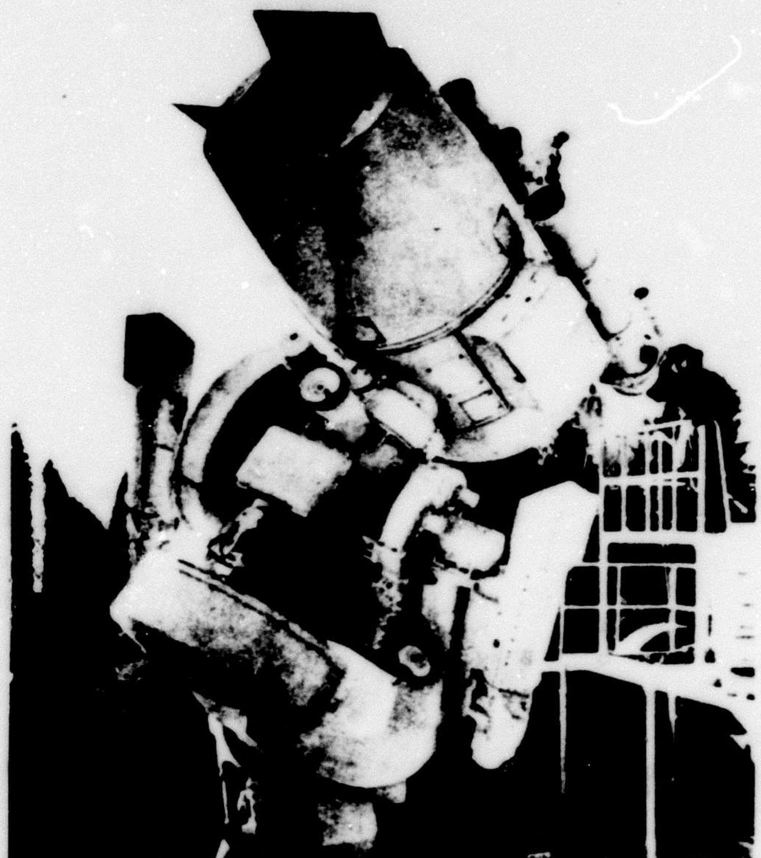

Fig. 14. General view of the VAU Camera.

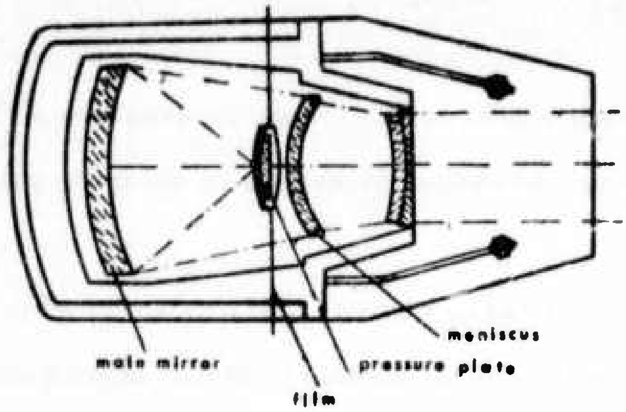

Fig. 15. Optical schematic of VAU [26].

The technical specifications of the VAU satellite tracking camera are as follows:

Objective - "Astrodar" lens, designed in 1958 at the Pulkovo Observatory by D. D. Maksutov and M. A. Sosnina, with:

Effective aperture, 500 mm;

Focal length, 700 mm;

Effective relative aperture; 1:1.8;

Effective diameter of exit pupil, 390 mm;

Diameter of main mirror - 1070 mm;

Focal plane of camera - spherical, with radius of curvature of 700 mm;

Diameter of circle of aberration in the field - 0.03 mm;

Field of view - $5^{\circ} \times 30^{\circ}$ rectangle;

Obturator shutter - used to obtain discontinuous images of the tracks of reference stars or bright satellites and controls the registration of the precise time system;

Leaf-type shutter - opens and closes in 0.02 second; used to limit the number of track segments and makes it possible to determine the star track breaks corresponding to a fixed moment in time;

Film - 70 mm wide (frame size, 326 x 61 mm) [4];

Photograph size - 60 x 360 mm.

The surfaces of the meniscus of the main mirror and of the pressure table are portions of concentric spheres having a common center of curvature.

Camera mount - electrodriven [4], triaxial parallactic; unlike the usual equatorial mount, permits not only the pointing of the camera at any celestial point at which a satellite is located, but also the tracking in any direction of a satellite moving away from that point [1]. This is accomplished by rotating the camera on the circle to a point tangent to the trajectory of the satellite. The carry-over from one approximating circle to another is automatic, as set for any given program [2];

Tracking speed - 0-6000"/sec, making possible the tracking of deep space probes as well as of satellites;

Primary (right ascension) axis - directed toward the celestial pole;

Secondary (declination) axis - permits setting of the third orbital axis on any point on the selected circle of declination.

At the moment the photograph is taken, the camera rotates about the right ascension axis at the diurnal celestial rotation velocity and about the orbital axis at the rate of the apparent motion of the satellite. In photographing a bright or active satellite the camera is rotated only relative to the right-ascension axis.

The selsyn receivers [4] in the central panel make it possible to direct the orbital axis to the required point in accordance with the declination scale and the right ascension. Then an observation program is entered, which at the required moment in time, starts automatically to be executed by the instrument. The programming device controlling the motion of the camera about the orbital axis and the speed of the obturator shutter consists of 12 units, each of which assigns the positional angle, tracking rate and the moment the photograph is taken. Thus, the camera can track and photograph a satellite at 12 points along its apparent trajectory without observer participation. If desired, the position of the polar orbit can be changed at each point a photograph is taken.

<u>View finders</u> - The camera has three view finders, one of which is angular. The observer can use any of them, depending on the camera position. Each view finder has interchangeable magnifications of 25, 50, and 100 with corresponding fields of view of $2^\circ 40'$, $1^0 24'$ and $52'$, respectively*. With them, the observer can control the moment of appearance of a satellite having a stellar magnitude of up to 12^M and the corresponding tracking speed of the satellite. The position of the polar orbit, the direction along the orbital angle, the tracking speed and the moment the shutter opens, can be corrected from a portable panel.

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* Tishchenko [4] says that "space objects are tracked using a 'straight' and an angle viewfinder and, automatically, with a photoguide. The 'straight' viewfinder has a magnification of 26 (field of view of $1^\circ 24'$) and of 115 (field of view of $49^\circ 24'$). The angle viewfinder and the photoguide are 10^M for fields of view of 7°."

Control panel. The camera is completely controlled from a central panel (Fig. 16 [8]) installed in a separate room, from which the entire equipment is visible.

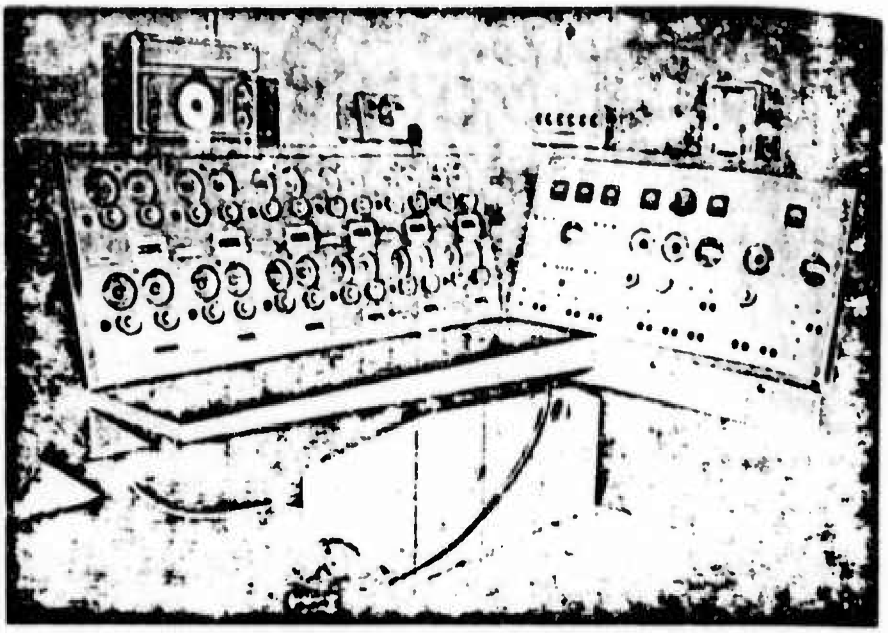

Fig. 16. Control panel of the VAU camera.

Photo guides. Photo guides, installed at both ends of the right-ascension axis fork, make it possible to automatically correct the diurnal motion of the camera along the right-ascension axis.

<u>Registration of the time the photograph is taken.</u>

The equipment used to register time was designed to register the moments of time when the photographs are taken with a 0.1 millisecond resolution and to produce a stable frequency of 50 Hz for driving the right-ascension axis. It consists of the following units:

1. Twin crystal oscillators, assuring a relative signal stability of not less than 1×10^{-8} per 48 hours of continuous operation. The frequency of the oscillators is 5 MHz;

2. The frequency divider operation is tri-parallel and is designed so that the time signals with their results register only when the output signals of at least two (of the three) of the identical units coincide;

3. Radio receiver, which with the aid of an oscillograph, makes possible the adjustment of the clocks to precise radio signals with a precision of not less than 0.3 millisecond [1], 6.3 milliseconds [2];

4. Electronic time scale unit, on which the pulses of the illuminated scale and the time registrations in the camera are formed;

5. An electronic clock, which assures registration of an instantaneous moment in time with the aid of digitized indicator lights, observed from all instrument rooms; and

6. A mechanical clock and cathode ray tube installed directly on the camera.

At the moment when the axis of the cross-connecting jumper of the obturator shutter coincides with the optical axis of the camera, the pulse-lamp flashes illuminating the dials of the mechanical clocks. As the photographs are taken, their readings are simultaneously registered on the edge of the frame (count accuracy of 0.01 sec), and the scanning of the cathode-ray tube is triggered. The tube images are in series with the images of the mechanical clocks, thus permitting time read-outs of up to 0.0001 sec.

A detailed analysis of the equipment and procedures used in registering time when the VAU camera is used to photograph artificial satellites is given in [3], and a table, compiled for use in determining time corrections of VAU photographs, is given in [14].

Photography process.

The photographic mode is selected as a function of satellite brightness and speed. There are four modes. The first is used to photograph fast-moving faint satellites. The camera is pointed at the required celestial point, is accelerated to match the apparent speed of the satellite, the obturator shutter begins to rotate, then the leaf-type shutter opens and the satellite exposure starts. The satellite image is obtained in the form of a point. Bright stars are obtained in the form of 5-gap tracks caused by the passage of the obturator lamella in front of the film. Time is registered at the moment when the center gap in the star track is located on the frame axis. Then the leaf-type shutter closes. The camera ceases to rotate about the orbital axis, the leaf-type shutter agains opens for a short interval of time and the star is photographed, including all faint ones in the entire field of the photograph. The satellite leaves almost no image on the film. If the observer does not see the satellite in the view finder, this process of photographing proceeds without its participation, i.e., it does not correct the direction and rate of motion of the camera, and the tumbler switch used to advance or delay the moment of photography is not switched on.

The second mode is used to photograph bright satellites that cannot be tracked by the camera. The instrument rotates only about the right ascension axis. The obturator shutter rotates at a speed proportional to the speed of the satellite motion, so that the gaps in the track of a bright satellite can be seen and measured. The leaf-type shutter opens and closes only once. Time is registered at the moment close to the center of the break in the satellite track.

The third mode is used to photograph faint, slow-moving satellites. It consists of the first half of the operations used during the first mode. An image of the star field is not required here since an adequate number of reference star tracks is obtained.

The fourth mode is used to track space probes. The obturator shutter does not rotate and the moment of the opening and shutting of the leaf-type shutter is registered by the printing chronograph on paper tape. In this case the star image is somewhat elongated and, under ideal conditions, the image of the object is obtained as a point.

Artificial satellites of $8\text{-}9^M$ (10^M according to [4]) and deep space probes to 13^M can be photographed with these cameras. Determinations of positions are precise to about 1 second of arc [2].

The precision with which satellite coordinates can be determined falls within the $1\text{-}1''.5$ range ($\sim$ 1 second of arc [2]) and time is measured with a precision of up to $0^s.001$ [4].

By 1970, this camera had been installed and was being tested at the Zvenigorod station near Moscow. The principal difference between the VAU and the Baker-Nunn cameras is that the parallactic mount of the VAU permits obtaining the reference stars as points in direct proximity to the satellite and to simultaneously photograph bright stars, thus making an essentially complete calculation of film deformation possible.

These cameras are reported to have been installed in 1970 in Tadzhikistan and in Armenia [1]. According to [2], the sites are somewhat more precisely located as being "near Dushanbe" and "near Erevan". A newspaper item [22], reports that a VAU camera (the third installed in the USSR) has been installed at the Gissar Astronomical Observatory near Dushanbe [24], in the Tadzhik SSR [22].

2. The TAFO-AL 75—AFU-75 Cameras (USSR)

a. The TAFO-AL 75 (Prototype of the AFU-75) Tracking Camera (USSR)

The TAFO-AL 75 camera (prototype of the AFU-75 tracking camera built in 1965) was designed and built in 1960 by K. Lapushka and M. Abele at Riga University. A significant amount of information on the design features, circuitry and preliminary results obtained with this camera is available in the literature. Because of this fact and also because the

Soviet literature either does not contain complete data on the changes made in this instrument in designing the AFU-75, or because references cited in the literature are presently unavailable, a summary review of the design of the TAFO-AL 75 is given here to provide a means of identifying the differences between these instruments and to compare the more limited data (mainly descriptive) available for the AFU-75.

Fig. 17 is a photograph of the TAFO-AL 75 installed at the Riga tracking station No. 1084 [15].

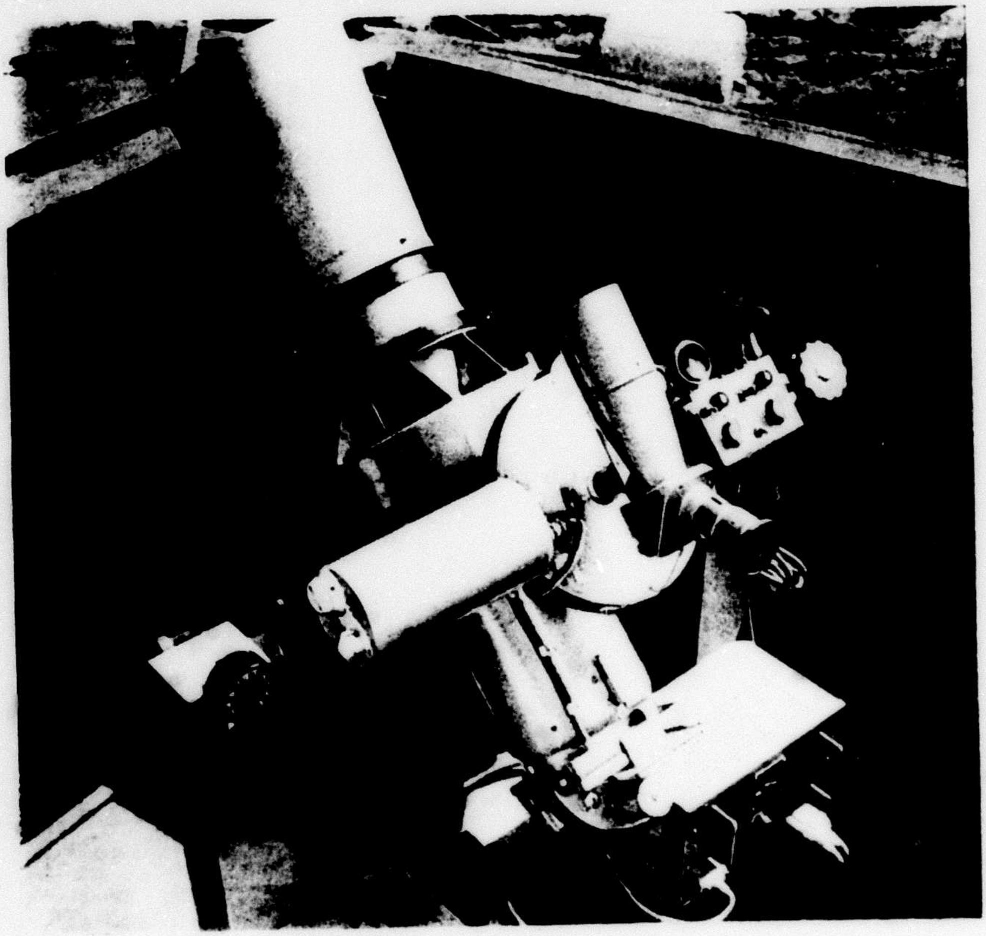

Fig. 17 The TAFO-AL 75 Camera

Abele, one of the inventors, gives the following operational schematic for this camera (Fig. 18). [16].

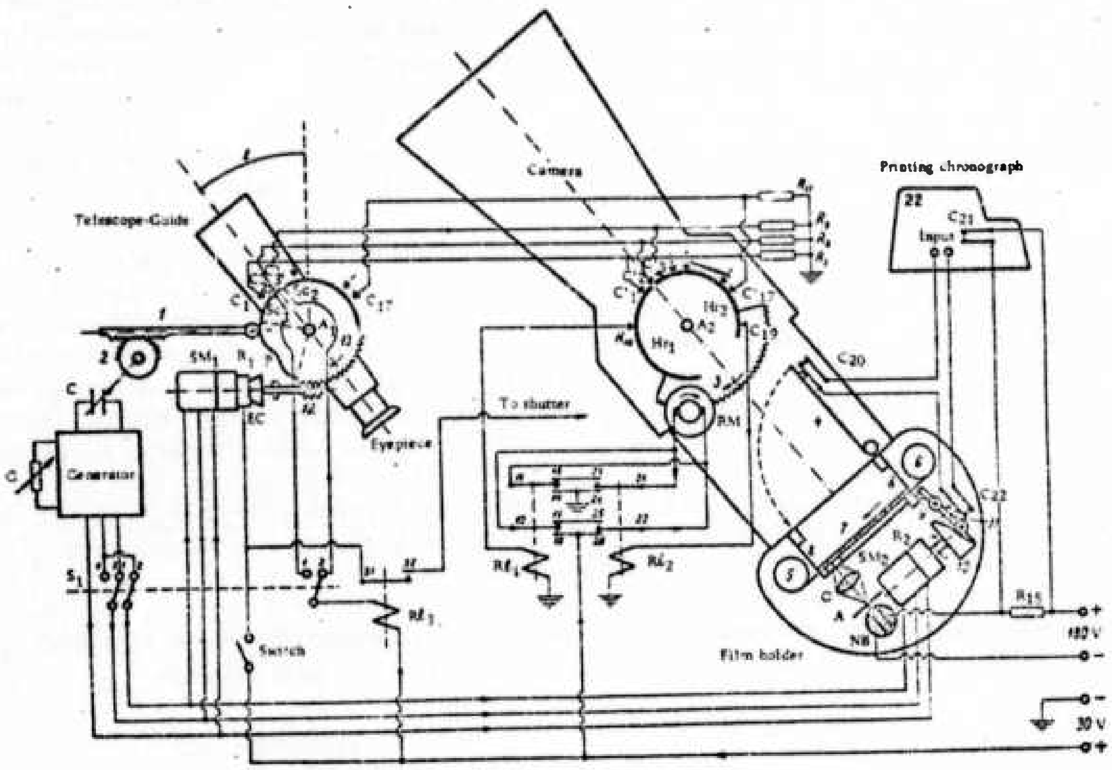

Fig. 18. Schematic of TAFO-AL 75 tracking camera [15].

Symbols: <u>Telescope - Guide:</u> A_1 - axis on which telescope-guide rotates; SM_1 - synchronous motor actuating telescope-guide through R_1 - reducer, and EC - electromagnetic clutch; 12 - worm gears, which rotate 13 - sector gear attached to telescope; G - generator supplying 3-phase a.c. to motor; (frequency changes proportionally to P - profile of 13, along which roller on 1 turns at end of 1 - rack); rotates 2- shaft gear on the axes of C - variable capacitors. NOTE: Profile of sector gear is such that the frequency f of the generator varies as a function of the angle ℓ in accordance with $f = f_0 \cos^2 \ell$, and the angular velocity of telescope rotation ω changes in accordance with $\omega = \omega_0 \cos^2 \ell$, where f_0 and ω_0 are the frequency and angular velocity of the telescope rotation at the point of culmination of the satellite.

Film-holder (60-mm film, clamped in a plane-parallel glass holder); SM_2 - film-holder motor (connected in parallel to SM_1); R2 - reducer; 10 - cam (ratio of lever arm is regulated so that if the satellite is observed in the guide crosshairs, the film turn rate coincides with the rate of image displacement in the focal plane of the objective; 11- roller arm (turns from cam; designed to produce trapezoidal wobble on axis; 9 - axis of arm; 7 - frame, which swings on 8, which is a flat spring; NB - neon bulb (d.c. supply); flashes appear on film as 4 points in a straight line; A - diaphragm aperture; O - small objective; NB light passes through R_{18} which is a large resistor (shorts out at 0.0005-sec intervals); C_{20}, C_{22} - contacts.

Chronograph: 22 - printing chronograph; C21 - chronograph contact. When time signals are chronograph print-outs, chronograph lag is determined by a special chronograph. In photographing very bright satellites, an obturator shutter located about 2 mm in front of the rotating film is used to make still photographs. At low obturator speeds (1-3 rev/sec), the obturator vane has a slot, which makes point images possible. The camera is rotated and the shutter is opened automatically.

Telescope-Guide—Camera Circuitry; Sc_1, Sc_2 - sliding contacts attached to 13, moving in accordance with C_1, C_2, ... C_{17} - fixed contacts, connected to C_1', C_2', ... C_{17}' - contacts, along which Hr_1, Hr_2 - half-rings, slide (rotate with camera rotation); $R\ell_3$ - relay (winding); current across Sc1 or Sc2 depends on position of S_1 - switch, determined by telescope rotation; $R\ell_1$, $R\ell_2$ - relays; RM - reversible motor; R_3 - resistor; A_2 - axis of camera.

Technical Specifications: Objective: 7-lens "Uran- 6"; f = 75 cm, D/f = 1:3.5; resolution in center of field, 32 lines/mm. Film: photograph size, $4^{\circ} \times 4^{\circ}$; distance between frame centers, 7°; 17 photographs per satellite pass, each photograph registering 4-6 satellite images. Camera mount, triaxial. Telescope-guide can be rotated on third axis independently of the camera.

With the "Uran-16" lens and for exposure times of 1 sec, images of stars to 10.4 stellar magnitude can be obtained. With compensation, the effective exposure for a satellite can be increased by a factor of 70. Stars having the limiting brightness are 35 μ in size on the photographs. Limiting stellar magnitudes, calculated for different exposures, are tabulated in Table (9).

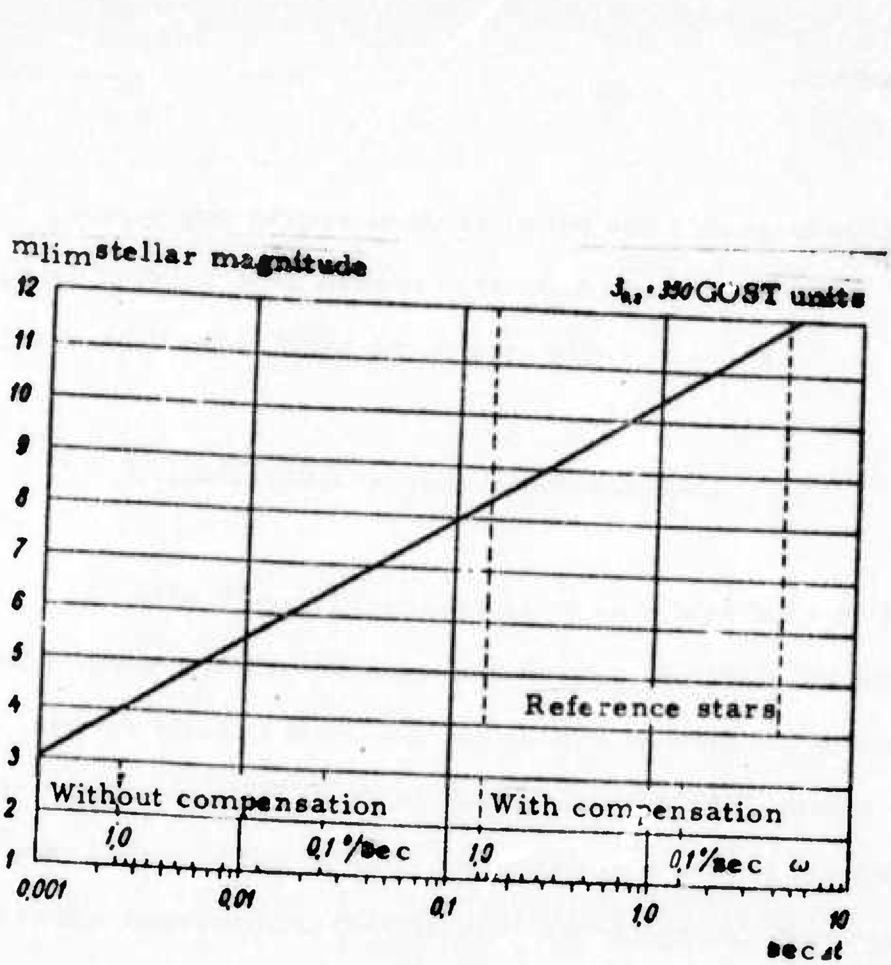

Table 9. Stellar magnitudes of reference stars calculated for photographic exposures.

First Results Obtained with the TAFO-AL 75 [15].

The camera was installed in July 1961 and regular observations were begun in August. By 1 December 1962, approximately 120 negatives good enough for precise processing had been obtained (observed "Midas-3", "Transit-4A" and "Echo-1"). From preliminary processing of a small number of photographs, using a UIM-21 microscopic rule, with subsequent reductions made by the Schlesinger method (3 reference stars), the precision of determining satellite coordinates was found to be ± 0."5-1."0.

Systematic errors in these coordinates were attributed, at least in part, to the uneven motion of the film holder. These discrepancies were found to have an r.m.s. error of $\pm$ 1."4.

b. The AFU-75 Tracking Camera (USSR)

The AFU-75 satellite tracking camera was built by K. Lapushka and M. Abele in 1965 at Riga University. By 1967, an AFU-75 camera had been installed at the Uzhgorod station as well. The first satellite observation program in which these cameras were used consisted of regular observations of the "GEOS" satellites as a part of the USSR contribution to the international Smithsonian Astrophysical Observatory program [1].

Examination of photographs taken at a number of stations over the past several years (1967-1974) suggests that various design changes may have been made in the original model. Specific information, substantiating these changes in external appearance, especially in the camera mount, has been found in the literature only in limited form and only for the so-called "expeditionary" model mentioned as being used at field stations in Africa.

Photographs showing some of these changes are given in the following figures (Figs. 19 to 22, inclusive).

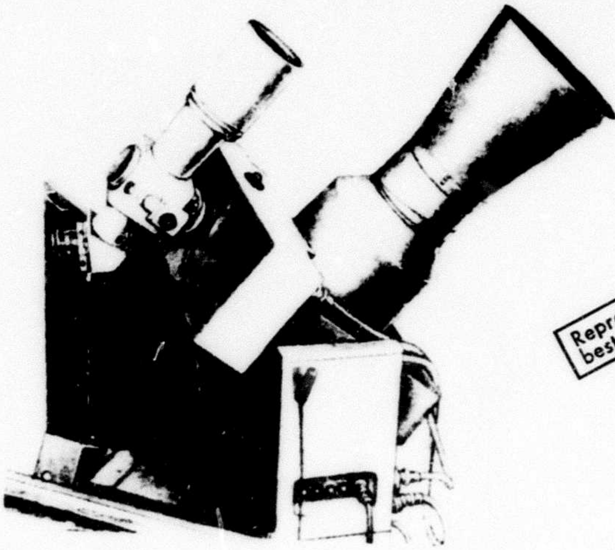

Fig. 19 . General view of an early model of the AFU-75 tracking camera [4].

Note: A photograph of the AFU-75 at the Astronomical Institute, Uzbek Academy of Sciences, appears to be this same model [27].

Fig. 20. The AFU-75 (left) and SBG [?] (right) installed at Zvenigorod [28].

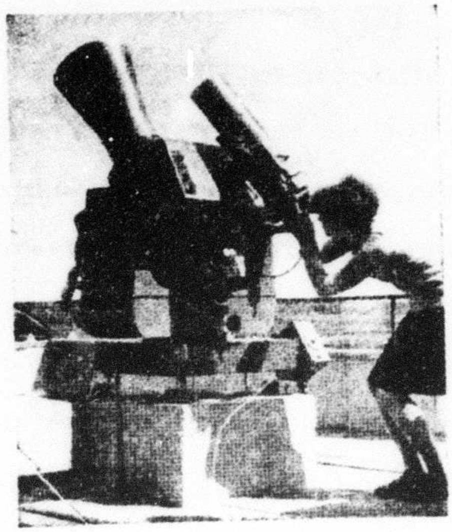

Fig. 21. The standard "expeditionary" AFU-75 camera [25].

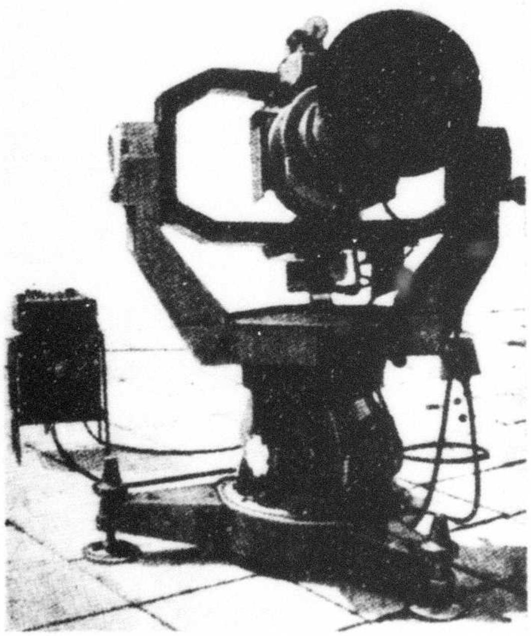

Fig. 22. Automatic installation of the AFU-75 camera [29].

This camera was designed primarily for satellite geodesy purposes, i.e., to photograph satellites in the 3-10 stellar magnitude range [1] (to 9^M [2]; to 8^M [4]) within the limits of the apparent orbital arc even when only approximate ephemeris data are available. Objects that are not visible in the telescope guide cannot be photographed. The wide range of frequencies of the generator, which drives the motor of the telescope guide and the compensation mechanism, make it possible to photograph an object having an apparent angular velocity in the $0\overset{\circ}{.}02$ - $1\overset{\circ}{.}5$/sec range. With a minor change to the maximum frequency in the generator schematic, the observer can photograph the object much more quickly. In actual instruments, the upper limits of the angular velocity of the guide telescope are not identical and may vary between $1\overset{\circ}{.}1$ to $1\overset{\circ}{.}6$/sec.

Lapushka [17], writing in 1970, gave a preliminary list of the possible uses* of this camera in satellite geodesy, as follows:

1. Observations for space geodesy;
   Practical applications: observations of active GEOS-1 and GEOS-2; observations of passive AES; observations of faint high-altitude AES; can be used to make geodetic connections by an orbital method;**

* A detailed description of all of the possible operational modes is reported to have been published in "Nablyudeniya ISZ", no. 9, Warsaw, 1969 (not available as this report is being written).

** Detailed descriptions of the methods used to photograph faint and bright satellites and to process photographs of active AES are given in references [1], [2], [10], and [18].

2. Observation for studying the properties of the upper atmosphere (e.g., SPIN and INTEROBS programs);*

3. Comparison and checking of visual observations;

4. Observations of unknown objects (the ready mobility and the fact that pre-programming is not necessary make it possible for an experienced observer to set the camera axis and regulate its tracking speed so that a photograph of the object can be taken); and

5. Observations for the Ephemeris Service; the high resolution of the AFU-75 makes it possible to use it in improving satellite orbits.

In connection with (4) above, there is some evidence that the AFU-75 camera may be being investigated to determine its possible adaptability for intelligence-type operations. Such an application is suggested in a recent (1972) paper by V. A. Yurevich [12] of the USSR Academy of Sciences Astronomic Council, which describes a method by which reasonably accurate, preliminary coordinates of artifical earth satellites can be

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* Masevich et al [2] note that "in the near future, a 4-channel photoelectric photometer is to be installed on the AFU-75".

determined from AFU-75 photographs in a relatively short period of time, i.e., determined two-three hours after the photographs are taken and with accuracies in position on the order of 2'-3', and $0^s.01$ in time.

Technical Specifications

The technical characteristics of the AFU-75, as reported by various authors, are as follows:

Objective: Uran-16 type, 7-lens (d/f = 1:3.5) [1, 8];
field of view, $10^\circ \times 14^\circ$ [1, 2, 8]; $15^\circ \times 10^\circ$ [23];
focal length, 736 mm [1, 2, 8]; 735 mm [3]; 75 cm [23];
diameter, 210 mm [1, 2, 8];
aperture, 21 cm [23];
Film: 190 mm wide; automatic rewind [1, 2, 8].
Film holder: contains 29-m film (110 negatives) [1, 2, 8]; a photochronograph in the film holder gives on the film the instantaneous image of the rotating dials illuminated by a flash lamp
Central shutter: slow-action (automatic rewind) [1, 2, 8];
Mount: 4-axis: permits tracking of satellite along arc of small circle [1, 2], using only one axis [2];

Automatic time registration equipment:
Crystal clock (1), KCH-IV [7];
Oscillograph [1];

Multiband radioreceiver [1], and "other devices which assure its operational independence on expeditions" [2];

Dimensions of AFU-75 set: 1.5 x 2 m [1, 2];

Weight of AFU-75 set: 350 kg [1, 2];

Power supply required: 200 V, 50 Hz, 2 kw;

Equatorial platform: entire camera sets on this platform, which is in itself a device for tracking diurnal rotation over a period of 2-3 minutes. This platform is described as an original design, which is used for no other existing satellite cameras [1, 8]. (Fig. 23).

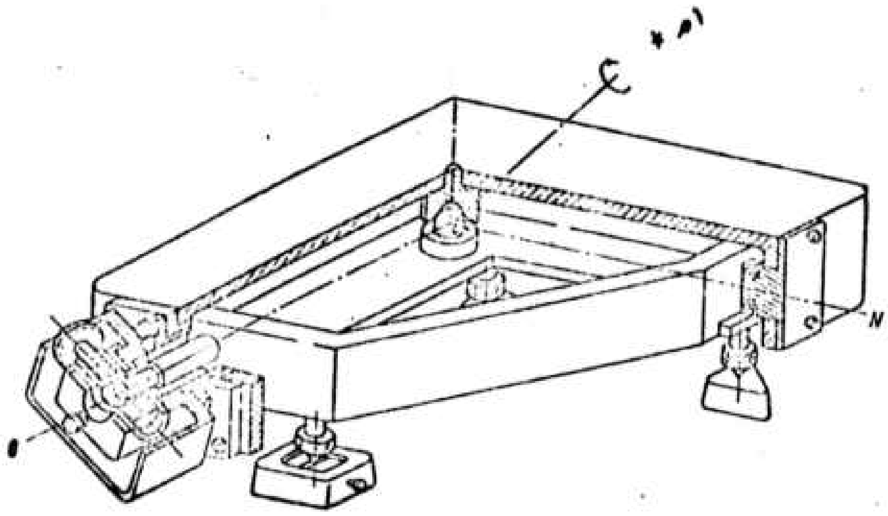

Fig. 23. Equatorial platform for the AFU-75 camera.

Here it is interesting to note that Lozinskiy [7] in a 1972 paper states that at the so-called "expeditionary" stations, round-the-clock electric power is not always available and that the small UD-2 engine provided with the AFU-75 sets under these circumstances is the only source of power. In practice, the observer must start the engine two hours prior to the time radio signals are to be received and he is forced to stay close to the engine at all times, "time which might better be spent in other work".

A method employed at the Afgoi (Somali) station to overcome this drawback and simplify the observer's work consisted in the addition of a transistorized TKN-33 clock to the circuit. This clock requires less than 0.5 amp and can be powered from both a.c. or 12-V d.c. current generated by a 100 a-hr nickel-cadmium storage battery, or sufficient power to operate this clock for eight days without recharging. At Afgoi this clock was used to power the time registration equipment and also as a source of 100-kHz stable frequency for supplying the frequency divider with 100 kHz - 1 Hz for the KCh-IV clock lamps. The 1 MHz tube of the crystal oscillator was eliminated from the circuit. The output signal "60^x" of the TKN-33 clock is connected to the oscillograph.

A recently-obtained Soviet patent [19], entitled a photoelectric tracking device, described by an abstractor [21] as a photoguide, "provides a circuit diagram and description of the circuitry controlling the telescope-guide, compensation mechanism and camera operation in the automatic tracking of objects", i.e., automatically varies the mismatch time of signal reception and the step of the motor as a function of image brightness.

This circuitry is described as representing a considerable simplification over that used previously, is more sensitive in tracking faint objects, and operates faster in tracking bright objects.

Comparison of this schematic and description (see below) with those given on pages 121-126 for the TAFO-Al 75 (prototype of the AFU-75), shows that the new patent is a considerable simplification in circuitry over that of the TAFO-Al 75. In addition, the description of the AFU-75 operation given in [1] also suggests the applicability of this patent to the guidance system of the AFU-75.

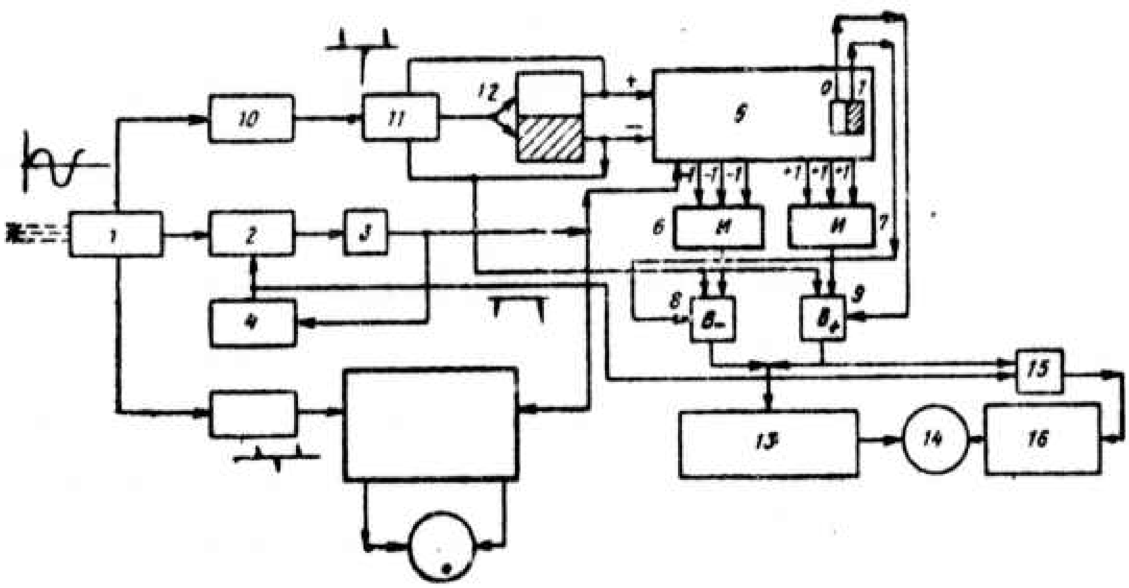

Fig. 24. Circuitry for tracking device.

1- Generator; 2- Photoreceiver; 3- Amplifier unit (discriminator + shaper); 4- AFC of pulse repetition rate as function of change in object brightness; 5- Reversible counter; 6-9 - Coincidence circuits; 10 - standard pulse shaper; 11- Logic circuit; 12- Trigger controlling adding and subtracting operations of 5; 13- Logic circuit connecting power to motor 14; 14- Motor; 15- Circuit regulating signal delay; 16- Logic circuit actuating telescope motor:
(Note: 5-16. Electronic circuits discriminating signals carrying information on object position relative to axis of device in terms of each coordinate.)

As the schematic indicates, the simplifications in circuitry and tracking accuracy improvements are realized by the connection, through an amplifier, of 1) the inputs of the reversible counters in the signal-discriminating circuits to the photoreceiver output, 2) the summing and subtracting counter nodes through a switching unit having a corresponding reference voltage generator winding, 3) connection of counter outputs to two logic circuits, and 4) the remaining two counter inputs, to the output units of the synchronous switching output unit and the outputs of the automatic frequency control system (for each coordinate).

Masevich and Lozinskiy [1] described the AFU-75 telescope-guide, image-shift compensation mechanism and camera operations as follows:

Telescope-guide (d = 120 mm; 8^M and 20^M for fields of view of 6° and 3°, respectively [1])- used to control the pointing of the camera on the satellite and to visually check the accuracy with which the rate of compensation and the velocity of the satellite are matched. The guide is turned by means of a special drive mechanism, which has a frictional variator for matching the guide rate to the film speed along the large and small circles within the limits of one photograph*; [1].

* A method of determining the zero point of the speed variator of this telescope guide is described by Ye. A. Yurov [11]. The largest relative error of this method is given as ~0.5%.

The satellite image - shift compensation mechanism, set in the focal plane of the camera, consists of a metal frame with a fixed plane-parallel glass plate. The surface of the plate farthest from the objective lens corresponds to the focal plane. The film is flattened with a metal pressure plate. The frame containing the film moves 36 mm along the guide track, which can be subdivided into 12 segments (3 mm each), 6 segments (6 mm each), 3 segments (12 mm each) or 2 segments (18 mm each). Motion is actuated by a synchronous motor similar to the one used to drive the guide. Both motors operate in parallel from the same generator, the frequency varying with the program [1].

Photographic Procedures

The first step in photographing satellites with the AFU-75 is to make exposures of the reference stars. At this time the equatorial platform is operating, the central shutter is open and the camera and compensation mechanism containing the film remain stationary. The time of the star exposure is assigned independently of satellite speed. After the star photograph is taken, the compensation mechanism begins to move in the direction along which the satellite image moves in the focal plane, at a rate equal to the image speed. At this time the satellite image appears as a point. If the compensation lasts for 3-6-12 mm, after this segment passes, the compensation mechanism stops for a new star exposure and then begins to move again, and so on until all 36 mm have passed (i. e., 12-6-3 times, respectively). The images of the star and the satellite are obtained in the form of straight chains of points. The number of point-images of the stars is one greater than the point images of the satellite, since each cycle begins with a star exposure. The main task of the observers is to precisely match the direction and rate of motion of the controlling telescope-guide to the direction and apparent velocity of the satellite. In order to accomplish this, the camera is equipped with all the required manual controls (levers) with which to operate it without the observer having to take his eye away from the guide. Photography begins only when, as the result of a change in the position of the pole of the apparent orbital arc and the velocity, the satellite image is motionless on the crosshairs in the field of view of the moving guide [1].

In photographing bright satellites (to 3^{M}), the compensation mechanism is not engaged. The equatorial platform and the obturator shutter, which is a section of a cylinder with a slot, are in operation, completing one turn per second. Its rotation is synchronized with the pulsed seconds of the crystal clock and is controlled by it. The obturator shutter produces the gaps in the satellite track.* The time the photograph is taken is printed on the same photograph.

* Ya. K. Balodis [10], in a detailed study of the factors involved in time registrations in determining topocentric directions to bright satellites from AFU-75 photographs, criticizes the uneven motion of the obturator shutter of the camera.

The AFU also is used to photograph active satellites from distances of up to 3500 km for flashes of 15,000,000 candle power/sec. Here the equatorial platform is in operation and the central shutter opens on command by the observer. The stars and the images of the satellite flashes show up as points. By repeatedly opening the shutter, the observer can obtain the star images as two points, thus making it easier to differentiate them from the flash images.

Balodis, Lapushka and Lautseniyeks [18] provide the most detailed descriptions and photographic representations taken with the AFU-75 of active (GEOS) and faint passive satellites.

In photographing the flashes of active satellites with the AFU-75 camera, the images of the stars and of the satellite flashes appear as points on the photograph because when the shutter opens, the equatorial platform guarantees that the camera will follow the diurnal rotation. In order to differentiate between the star and flash images, a second exposure (slightly shifted) is made of the stars, giving an image such as that shown in Fig. 25. The topocentric spherical coordinates of the satellite flashes determined from such photographs are accompanied by rigorous determinations of moments of atomic time.

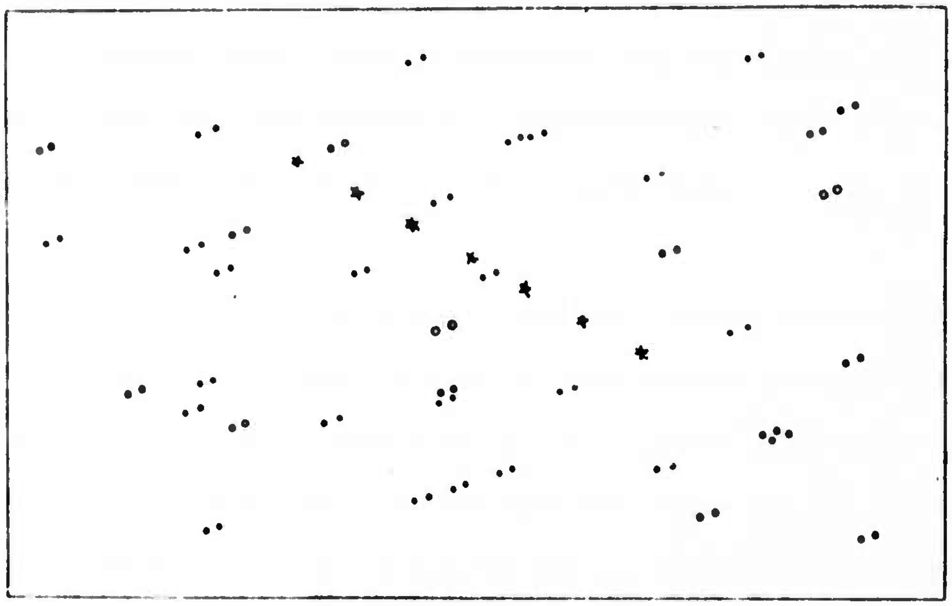

Fig. 25 Schematic representation of a photograph of GEOS-2 photographed with an AFU-75 camera. The symbols oo denote double exposures of stars, and *, exposures of GEOS flashes.

The equatorial plafform is also used in tracking faint passive satellites. When the camera shutter is opened the pressure "platform", together with the glass in the holder and the film pressed between them (called the "platform" for the sake of brevity) is immobile in the camera. The star exposures are made; the image of the satellite passes across the film emulsion and because the satellite is faint, it leaves no trace. When the star exposure is completed, the platform begins to move in such a way that the satellite image is immobile relative to the film and the satellite track shows up as a series of points. After a set distance, the platform stops and star images are again formed, but in another place, etc. In order to determine the spherical topocentric coordinates of the satellite points, the fundamental reference segments are the middle segments between the two adjacent positions of each reference star, closest in time to the moment of exposure of the satellite point.

Precise radio signals, and the crystal clocks with which they are compared, are used to register time before the observations are begun and after they are completed. A chronograph is installed on the AFU-75 camera and is synchronized with the crystal clocks. When photographs are made of faint satellites, the image of the time index (Figs. 26 and 27), is exposed on the film simultaneously with the star exposure. During the interval of time when the platform moves outside the light ray from the satellite as a function of the length of the path of the tracking platform, a specific number of equally-distributed flashes is produced, each of them occurring precisely for a hundredth of a second and, illuminating the chronograph, exposing its readings and the time indicator on the film. The time indicator simultaneously serves as the place the readings are made on the chronograph and as the readout for the distance the table moves.

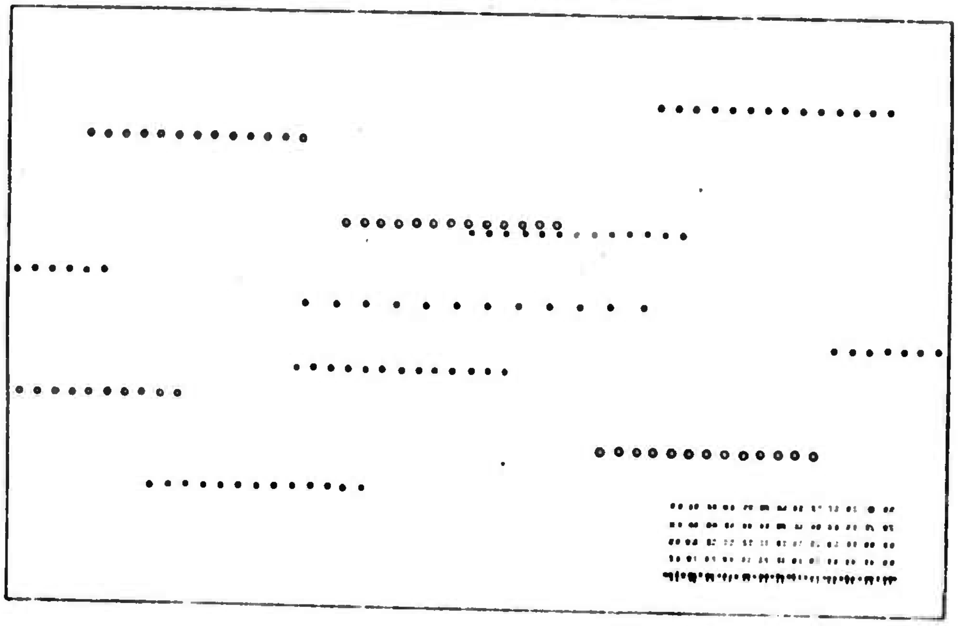

Fig. 26. Schematic representation of a photograph obtained with an AFU-75 camera in the mode of photographing faint satellites. Symbols: o - star position exposures; ● - points of exposure of a faint satellite; + - time indexes photographed at the time of star exposures; + " " " - time indexes and chronograph readouts photographed by the camera of the flash lamp at the time when the platform has tracked beyond the light beam in a faint satellite.

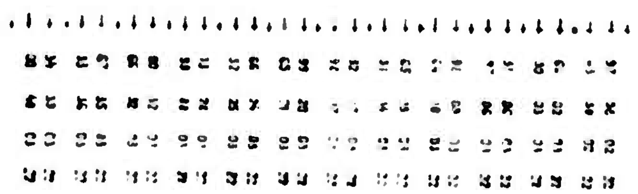

Fig. 27. Schematic drawing of the image of the time index and chronograph readings photographed by the AFU-75 camera for registration of the moments of time of precise exposures of satellites. Symbols: + - time indexes photographed at the time of star exposures (when the platform is motionless); + 97 58 02 22 - time indexes and chronograph readings photographed at moments when the flash lamp in the camera is operating at the time when the platform has moved beyond the light beam of the satellite. The chronograph reading is $22^h02^m58^s.97$.

The coordinates of the index points at the midpoint moment of the satellite exposure are calculated from the measured rectangular coordinates of the index image at the moment of star exposure, i.e., when the platform has moved one-half the distance. Calculating from the film the chronograph readings (accurately to a hundredth of a second) photographed while the platform is in motion, the mean moments of exposure of the satellite points are calculated from the index images corresponding to the measured rectangular coordinates.

Beginning in mid September 1969, an investigation was made of the possibility for photographing GEOS-2 with the AFU-75 camera operating in the faint satellite mode. The results showed that beginning at about 50° above the horizon, GEOS-2 could be photographed very well in this mode. By photographing it at the same moment that the on-board lamp flashed, the satellite was photographed on a single photograph in two different modes (Fig. 28).

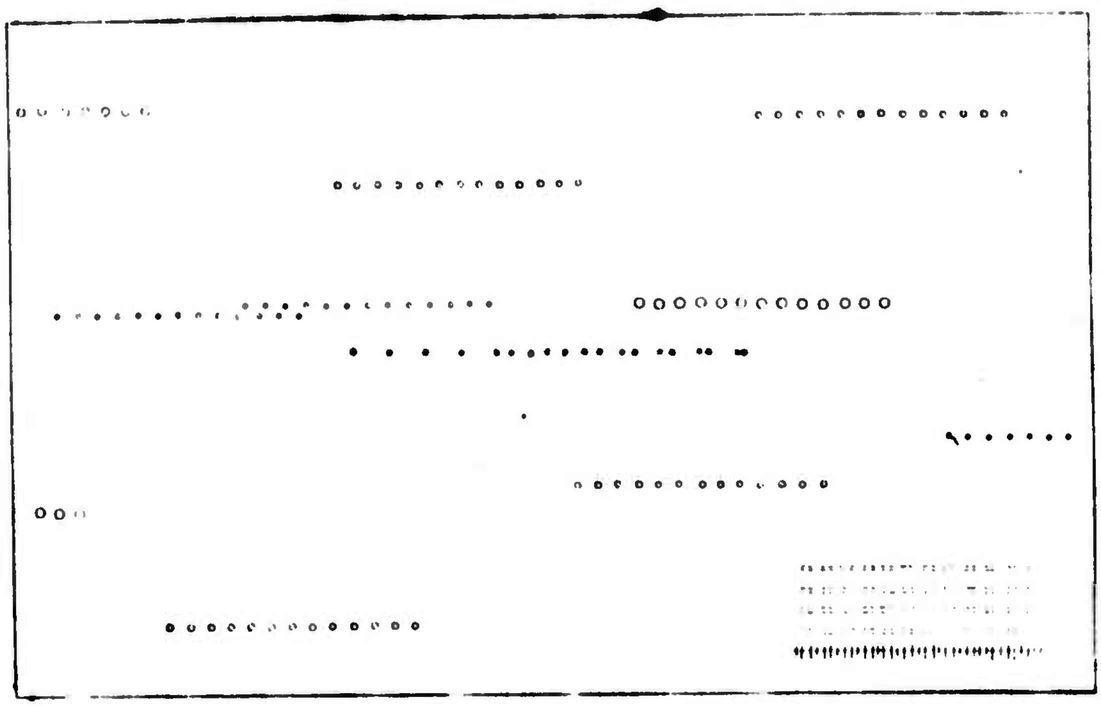

Fig. 28. Schematic representation of a photograph of the GEOS-2 satellite obtained in the faint-satellite photographic mode. Symbols: *-GEOS-2 flashes exposed on the film when star exposures are made with the platform motionless.

Observational Precisions

Satellite positions determi ed from AFU-75 photographs are precise to about 2 seconds of arc but, given a superior observer, may be about one second of arc [1]. Satellite directions are determined to ±2-3" [2]. Time registration is accurate to 1 millisecond [1, 2].

Sites of AFU-75 Satellite Tracking Camera Installations

USSR	Riga, Latvia	[29, p. 10]
	Uzhgorod	[29, p. 10]
	Zvenigorod (two models)	[34]
	Yuzhno-Sakhalinsk	[29, p. 10]
	Tashkent (Cent. Asia Univ., Astro. Obs.	[47]
Czechoslovakia	Ondrejov	[29, p. 12, 21]
Rumania	Bucharest	[29, p. 12]
Bulgaria	Sofiya	[29, p. 12, 21][36]
Hungary	Baja	[29, p. 12]
Poland	Poznan	[29, p. 10]
Africa	Cairo [Helwan], Egypt	[29, p. 10, 21]
	Khartoum	[30]
	Fort Lamy (Chad)	[30]
	Bamako	[30]
	Kerguelen Is.	[29, p. 21]
	Afgoi (Somali)	[29, p. 10]
Cuba	Santiago	[29, p. 21]
Mongolia	Ulan Bator	[29, p. 21]
Antarctic	Mirnyy	[38, p. 13]
	Vostok	[30]
	Molodezhnaya	[30]

French Guiana - "being installed:"[30]

Plans call for installations at:

Spitzbergen
S. Africa [30]

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PART V

SOVIET LASER GEODESY. THEORY AND EXPERIMENTATION

A. Soviet Contributions to the Theory and Scope of Soviet Laser Geodesy.

As Part I of this present report shows, the number of Soviet publications which contain information on Soviet laser geodesy represents a very small part of the total coverage of Soviet satellite geodesy literature (slightly more than 10%). Of this 10% coverage, the majority of papers, books and monographs deal with the instrumentation, methodology and results [sic] of lunar laser geodesy experiments. Most of the remaining publications either are proposals for the use of lasers or combined laser-photographic techniques in laying out space or ground geodetic networks (described in Part III), or are discussions of the theoretical bases of these methods and their applications as they affect the scope and direction of Soviet effort.

Examination of the available Soviet literature dealing with these theoretical problems and their applications reveals an interesting, but probably logical, dichotomy in the Soviet approach to and execution of Soviet laser geodesy projects, i. e., 1) the geodetic astronomy and geodetic gravimetry approaches and 2) the physics-astrophysics approach. The guidance, coordination and/or execution of the geodetic astronomy and gravimetry research and development have, for the most part, been the responsibility of the members of the USSR Academy of Sciences' Astronomical

Council and Institute of Theoretical Astronomy, and that for the physics-astrophysics aspects, the Lebedev Physics Institute and the Crimean Astrophysical Observatory. In both of these approaches, the research activities of the larger observatories have been of major significance.

1. Geodetic Astronomy - Geodetic Gravimetry Research

In general, one can say, with considerable justification, that the staffs, programs and publications of the Astronomic Council (Byulleten' stantsiy nablyudeniya iskusstvennykh sputnikov Zemli, its Nauchnyye informatsii), and the Byulleten' instituta teoreticheskoy astronomii) represent the continuation of the basic research and development of theoretical and applied studies in geodetic astronomy and geodetic gravimetry, which were carried out in the late 1940's and the 1950's and which have been recognized as major contributions to and were the forerunners of the Soviet guided missile program. Here, papers by D. V. Zagrebin, A. A. Izotov, L. P. Pellinen, and especially those of I. D. Zhongolovich are some examples of the continuity of Soviet geodetic research and development.

During the late 1950's, immediately prior to and after the launching of the first Soviet satellites, the Astronomical Council programs were concentrated on the development of the Soviet satellite observation station network. Initially, this effort involved responsibility for the entire program and included 1) the selection of appropriate sites for the visual and photographic observation stations (73 stations had been established by the time the first Soviet satellite, 1957 β, was launched); 2) provision of observational equipment; 3) preparation of training manuals covering observation methods and instrument operations; 4) conducting of training programs for station observers, including the sponsorship of major seminars; 5) organization of data processing methods and facilities*, and 6) research and development of satellite cameras and camera operation methods.

At the Institute of Theoretical Astronomy, studies of a more theoretical nature were in progress. By 1960, geodetic gravimetry papers by I. D. Zhongolovich, a major contributor to the basic geodetic gravimetry concepts of the USSR guided missile programs of the late 1940's and 1950's, had described the methods used and the results obtained in an experiment in determining some of the parameters of the gravitational field of the earth from observations of the 1957 β_2, 1958 δ and 1958 δ_2 satellites [1], and had analyzed the satellite perturbations caused by the asymmetry of the North and South Poles of the earth [2]. In the field of geodetic astronomy, Zhongolovich published in 1961 a general paper in which he defined the role of satellites in geodesy [3], and in 1962, a more specific paper analyzing the coordinate systems used in studying the motions of artifical earth satellites [4].

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* Soviet reports have repeatedly acknowledged the inadequacy of computer facilities in the USSR satellite geodesy programs.

By 1965, Zhongolovich had published a paper on the determination of satellite positions from synchronous photographic observations [5]. These papers were followed in 1968 by two papers by Zhongolovich, elaborating on the synchronous pair method as applied to particular cases of observation conditions [6, 7] and, together with those of other scientists dealing with various problems involved in making synchronous observations*, provided the basic information required to adapt these methods to laser geodesy when geodetic lasers and higher-precision cameras became available in the Soviet Union. These methods were suggested for use on such projects as the USSR "Arctic-Antarctic geodetic vector traverse project " [12, 13, 14] and the establishment of a world-wide satellite geodetic network [15], proposed by Zhongolovich in 1970, 1971 and 1972 (for details see Part III). Papers written by such scientists as Masevich suggest that these methods were also applied in the implementation of Soviet contributions to such international geodetic projects as the ISAGEX, INTEROBS and SPIN programs.

Another major contribution was made in 1969 by Zhongolovich in the geodetic astronomy field (fundamental geodetic constants), in a paper defining the relationship of the motion of the terrestrial poles to astronomic-geodetic operations [16].

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* V. M. Amelin, USSR Institute of Theoretical Astronomy, (1962) [VIII]; M. Schädlich, GDR (1969) [IX]; B. M. Klenitskiy, USSR Geodetic Service (1969) [X]; V. A. Firago, USSR Main Astronomical Observatory (1970) [XI].

Although the principal aim of the present report is to summarize information on the Soviet contributions to satellite geodesy, papers written by scientists from the eastern European countries, either independently or in collaboration with Soviet scientists on joint projects with Soviet institutions, have been of significance in many cases. For instance, in the field of theoretical geodesy the papers published in 1969 by K. Arnold of the Potsdam Geodetic Institute (GDR) on the determination of the figure and gravitational field of the earth [17] and that by V. G. Shkodrov, jointly prepared by the USSR Institute of Theoretical Astronomy and the Bulgarian Academy of Sciences, on the errors involved in the determination of the earth's potential from gravity measurements on a known surface [18], are noteworthy.

2. Physics-Astrophysics Research

The reason that a small group of Soviet physicists and astrophysicists entered the realm of satellite laser geodesy apparently was, at least in part, the result of the experimental work carried out by them during or immediately after the development of the laser used in the first lunar ranging project. This group consisted of such staff members of the Lebedev Physics Institute and the Crimean Astrophysical Observatory as N. G. Basov, one of the authors of a 1967 paper describing the first USSR laser ($N^{14}H_3$) frequency standard used in satellite observations [19], Yu. Kokurin, V. V. Kurbasov, V. F. Lobanov, V. M. Mozhzherin, A. N. Sukhanovskiy and N. S. Chernykh, many of whom were associated with the first Soviet-French lunar ranging experiment. During the 1966-1968 period, this group published at least four theoretical papers on topics formerly considered to be the province of geodetic astronomers. It is a matter of some interest that these papers include references to the work of American, English, German and French geodetic astronomers, but none cites the research of such famous USSR geodetic astronomers and gravimetrists as Zhongolovich and Izotov.

The first of these four papers by Kokurin et al was published in 1966 [20] and deals with the possibility of measuring the parameters of the lunar orbit (distance between the centers of mass of the moon and of the earth, orbit eccentricity) and the figure of the moon (radius of moon, i.e., "frontal" radius). Pointing out the large divergences in these values "recently"* obtained by several scientists, they estimate the improvements in precision which could be obtained by using laser-ranging techniques with a corner reflector set on the moon. Assuming that the earth-lunar reflector distance can be measured with a $\pm$ 3 m precision, and taking into account constraints imposed by the energy of the laser transmitter and the laser beam divergence in the atmosphere, these authors anticipate that more precise values could be obtained for distances to the moon, lunar parallax, the equatorial radius of the earth and the radius vector of the point of observation. With a ruby laser, whose pulse duration is $\sim 10^{-8}$ sec and an energy of several joules, an astronomic telescope at least 1 m in diameter, and an observation session lasting $\sim$8 hours, Kokurin et al postulated that a 1.5-3 m precision of the laser-lunar reflector distance would be possible.

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* i.e., prior to 1966.

In the following year (1967) these same scientists (with the exception of Mozhzherin) published a continuation and elaboration of the 1966 paper [21] in which mathematical formulas are derived for: 1) determination of the ΔT correction (ephemeris time minus U. T.) and of the radius vector of the observation station; 2) determination of lunar orbit eccentricity and the mean distance between the centers of mass of the earth and moon; and 3) determination of the radius vector and selenographic coordinates of the point being observed by laser ranging techniques.

Again, assuming that the ground station-lunar reflector distances can be determined by laser techniques with an error of $\sim\pm 3$ m, and taking specific moments in time, the authors calculated numerical examples by the proposed formulas to determine the extent to which the various parameters could be corrected by ranging measurements to a reflector set on the moon. The results showed that if all of the following parameters contained in the initial formulas are known with sufficient precision, where

a_o - equatorial radius of the earth;

δ, t, π - declination, local right ascension, lunar parallax;

ℓ, b - selenographic longitude and latitude of the point being observed by laser ranging;

ℓ_o, b_o - librations of moon in longitude and latitude, with topocentric corrections taken into account;

Δ_1 - instantaneous distance between the centers of mass of the earth and moon;

Δ_i' - topocentric distance between the observation station and the center of the moon;

Δ_o - mean distance between the centers of mass;

e - eccentricity;

φ' - geographic latitude of the observation station;

r - height of point being observed by laser ranging; and

D_i - distance measured at some moment in time between observation stations and the lunar-ranged point,

the authors' formulas gave total errors as shown in the following Table:

Table 10.

$\delta\,(\delta\Delta_o)$	δ (dr)	δ (de)	δ (dℓ)	δ (dρ)	δ (dt)	δ (db)
~300 m	~300 m	$\sim 2 \cdot 10^{-8}$	~15''	7-10 m	0.02^s	~15''

The theoretical expositions presented in the two early papers mentioned above were further supplemented by the publication in 1968 of a paper by Kokurin and Lobanov [22], in which a "new" method is proposed for studying the physical libration of the moon. Their derivations and a numerical example showed that the use of simultaneous laser measurements of the distances between an observation station on the earth to two fixed points on the lunar surface permitted more precise determination of the physical libration parameters τ - longitude, ρ - node, and σ - obliquity, that are related to distance measurements.

The fourth paper in this series was written by the French scientist M. D. Polanouére, and published in the Byulleten' instituta teoreticheskoy astronomii in 1970 in Russian [23]. In this paper, Polanouére, also assuming a precise ground-to-moon distance, investigates the possibilities offered by laser ranging techniques, and derives equations which improve the precision with which those parameters determining lunar translational and rotational motions and the lunar figure, can be determined; i.e.,

1) elements of the lunar orbit, with particular reference to the center of lunar inertia-observer distance, and the ecliptical coordinates of the center of inertia of the moon, $\beta_{☾}$, $\lambda_{☾}$;

2) elements of the physical libration of the moon, particularly in the Euler angles φ, θ, ψ;

3) geocentric coordinates of the observer, φ', λ, R_A; and

4) selenographic coordinates of the observed point on the lunar surface, β_B, λ_B, r_B.

In an analysis of observation reduction methods, Polanouére also makes a selection of lunar positions best suited to the derivation of optimum parameter corrections.

3. Geodetic Research

The principal geodetic research and development organizations in the Soviet Union are the Central Scientific Research Institute of Geodesy, Aerial Mapping and Cartography (TsNIIGAiK), the Moscow Institute of Geodetic Aerial Mapping and Cartographic Engineers (MIIGAiK) and the Novosibirsk Institute of Geodetic, Aerial Mapping and Cartographic Engineers (NIIGAiK). Each of these institutes publishes an irregular journal, a Trudy, which almost without exception is published in such small editions that its issues are rarely received in the United States. Information on the contents of these journals is, however, generally available in the form of abstracts published in the Soviet abstract journal, Referativnyy Zhurnal. Geodeziya. Some additional data are published in the Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli.

NIIGAiK. This institute appears to be the only geodetic institution participating in the Soviet satellite visual and photographic observation programs. As such, the Soviet authorities first designated this station as no. 35 in their original network, subsequently changing it to no. 1035 in compliance with the COSPAR agreement. The available literature indicates that, in addition to regular reporting of tracking data, two members of the institute's staff, V. Merkushev and Yu. V. Surnin, frequently contributed papers to satellite geodesy publications. Over the 1961-1967 period, Merkushev wrote at least eight papers on observation techniques and instrumentation. In the 1967-1972 period Surnin published at least seven papers on methods of determining geodetic satellite orbital motions. Neither investigator mentions or discusses laser applications.

That some Soviet geodesists, particularly those at the TsNIIGAiK and MIIGAiK and the Main Administration of Geodesy and Cartography (GUGK), were aware, in varying degrees, of the development of laser technology in both the USSR and/or in the western nations, as well as its applications to satellite geodesy, is demonstrated in papers written by some of the staff members of these institutions.

MIIGAiK. One of the earliest of these papers was written by Yu. M. Klimkov of the MIIGAiK in 1966 (published in 1967)[24], at a time when Kokurin et al were in the process of publishing their first papers on laser applications in satellite geodesy. Apparently unaware of this research, Klimkov's paper presents a general discussion of laser radiation characteristics, enumerates and gives the major characteristics of the principal types of lasers (solid state, gas, and semiconductor), and analyzes the optimum methods of measuring distances of three geodetic sides, recommending the following methods of making these measurements:

1) precise measurements of short distances (to several hundreds of meters), interferometer methods;

2) precise measurements of intermediate-length distances (to several kilometers), phase methods; and

3) high-precision measurements of long distances (> 100 km), pulse methods.

TsNIIGAiK. As late as 1968, on the occacion of a seminar on the geodetic processing of AES observations, held in Tashkent from 23-25 November, two leading geodesists representing the TsNIIGAiK presented papers describing methods of joint processing of ground and space triangulation [Pellinen, 25]; the joint adjustment of gravimetric and satellite data in determining the gravitational field of the earth [Pellinen, 26]; and the construction of a coordinate system referred to the center of mass of the earth [Izotov, 27]. Although these papers can be considered as applicable to some aspects of laser geodesy, no direct references are made to this fact.

USSR "Geodetic Service". V. M. Klenitskiy, representing the "USSR Geodetic Service" at the above-mentioned seminar, presented a paper entitled, "Construction of space triangulation from chord directions and lengths", which described a method of determining space network directions and distances from simultaneous photographic and Doppler observations of satellites [28], again ignoring recent developments in laser geodesy by Kokurin and his colleagues.

By 1969, however, awareness of the publication of papers dealing with the application of laser technology to geodetic science, especially to those published in the west and in the geodetic astronomy journals, is demonstrated in a 1969 paper by O. S. Razumov, published in 1971 [29]. In this paper Razumov adapts and elaborates the method of synchronous observations proposed by Zhongolovich [3], to cover the use of laser observations, analyzing the distribution of errors in the 3-line observation method and discussing some of the problems occurring in making mathematical reductions of observations. Assuming that the laser observations are rigorously synchronous, he derives an expression for the r.m.s. tensor error in the positions of the end points of a vector relative to an initial station, calculates the influence of nonsynchronous observations on the total error of a chord vector, and points out the advantages realized if the systematic error of the chord vector is reduced when observations are made for at least two satellite passes across the chord.

Recent developments in laser geodesy made by both the geodetic astronomy and the physics-astrophysics groups of investigators is acknowledged in a paper by V. I. Medvedskiy, published in early 1972 [30], which discusses the construction of a space network by the line-angle method in two specific instances: 1) Three ground stations whose coordinates are known, equipped with a laser set up at one station, pointed on a balloon with a reflecting surface; 2) lasers installed at all three stations. Mathematical examples indicate that the tracking accuracy of laser ranging of the balloon satellite must be within 1/2 of the dispersion angle of the laser beam, the energy required for laser ranging to the satellite is about 5 joules, and that for photographing the satellite, ~300 joules.

B. Soviet Lunar Ranging Experiments

1. Early Experiments

Soviet scientists carried out two preliminary experiments in transmitting laser beams toward the moon. These first experiments were designed to test the feasibility of using laser beams for selenodetic purposes, as well as to investigate equipment and measurement procedures for possible future laser ranging projects. Both experiments were executed without lunar reflectors.

a. First Experiment

Site of Experiments: Lebedev Physics Institute, USSR Academy of Sciences.

Date: 13 September 1963, 0400 - 0532 hrs.

Laser target: Albategnius crater in the shadow portion of the moon.

Citing a paper by Smullin and Fiocco (Proceedings of the IRE, vol. 50, 1962), in which the authors had noted the applicability of lasers to ranging measurements, A. Z. Grasyuk and his coworkers at the Lebedev Physics Institute and the Crimean Astrophysical Observatory of the USSR Academy of Sciences, published a paper in 1964* [31], which reported the preliminary results of the first Soviet lunar ranging experiment. This study was described by the authors as "an initial step in using laser techniques to investigate the parameters of the orbit and figure of the moon and of a number of other astronomic constants". This paper also contains a description of the equipment, a preliminary estimate of the signal-noise ratio and the results of earth-moon distance measurements, as summarized below.

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* This paper was originally presented at a colloquium held at the Lebedev Physics Institute on 28 September 1963.

Equipment

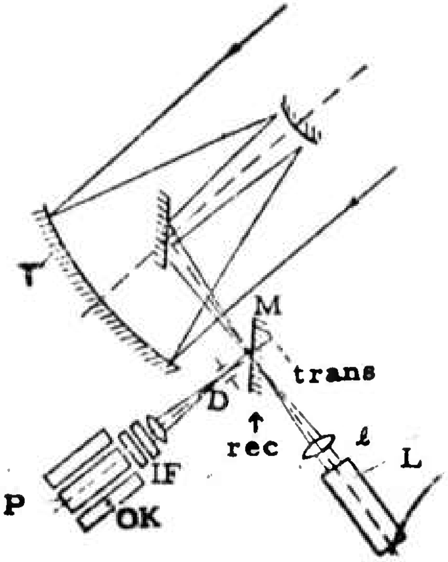

Fig. 29. Laser ranging equipment schematic.

T = Telescope; L = Laser (ruby); ℓ = Compatible lens; M = Reversible mirror; D = Diaphragm; IF = Interference filter; P = Photomultiplier; OK = Dry ice container; rec = Receiving position of mirror; trans = Transmitting position of mirror.

Laser Parameters - Ruby, developed by V. S. Zuyev and P. G. Kryukov:

Wavelength, 0.6943 Å

Pulse energy, 50 - 70 joules

Pulse duration, 2 msec; correction to distance error, ~150 km [33].

Beam diameter, 11 mm

Beam divergence, 3'.

Telescope parameters - Reflecting, used to transmit and receive signals, Coudé focus (f = 104 m);

Mirror diameter, 2.6 m;

Focal length of collecting lens, 32 cm;

Beam divergence at telescope exit, 0.5",

corresponding to a spot on the moon having a diameter $\leq$ 0.7 km, without beam divergence in the atmosphere taken into account (light scattering and backscattering and possible mismatching of apertures were taken into account);

Angular field of view of receiver, 8", corresponding to a spot 14 km in diameter on the moon;

Diameter of receiving diaphragm in the focal plane of the telescope, 4 mm.

Photomultiplier, used to receive reflected signals - cooled with dry ice to -76°, so that

quantized output = 0.04 - 0.05; dark current - 50 photoelectrons per sec.

Interference filter (coefficient of absorption - 0.5, bandpass = 20 Å), installed in front of the photocathode to reduce the signal-noise ratio;

Signal duration = 6 sec;

Signals registered with an oscillograph, triggered so that the onset of the reflected pulse coincided with the middle of the pulse train, the first half being used to measure noise and the second half to measure signal + noise;

Anticipated signal-noise ratio, 0.16 - 1.0.

Preliminary measurement results.

Thirty pulses were directed to the target, each signal lasting for 2 msec. The total time of signal storage was 60 msec; the average number of photoelectrons per pulse in the pulse train interval corresponding to the reflected signal was 6.2, and that of the noise was 4.67 ± 0.38, i.e., the magnitude of the noise determined in the first half of the 3-msec interval coincided with this value within the accuracy of the r.m.s. error. The magnitude of the pure signal was 1.53, i.e., four times greater than the r.m.s. error of the mean noise, indicating that laser reflections from the moon could be adequately registered against the noise background.

b. Second Experiment

(as reported by Kokurin and his colleagues [32, 33]).

Site of experiment: Lebedev Physics Institute;

Date: 19 October 1965; 0517-0547 hrs;

Laser target: bottom of Flammarion crater (selenographic coordinates - $\lambda = 3^\circ\!.57$, $\varphi = 2^\circ\!.98$); 82 pulses transmitted;

Equipment - Same as for Experiment 1 with the exception of the following:

ruby laser pulse energy, 5-7 joules;

pulse duration, 5×10^{-8} sec;

beam diameter, 13 mm;

telescope, primary mirror diameter, 2.6 m;

interference filter bandpass, 10 Å;

time registration, strobe (instead of oscillograph)

pulse duration, 150 microseconds.

Errors

instrumental = $\pm 10^{-7}$ sec;

due to signal analysis method, $\pm 10^{-6}$ sec;

signal divergence due to lunar relief, = 2×10^{-6} sec;

total anticipated error of half-width of signal, $\sim 2.5 \times 10^{-6}$ sec.

Results

The center of distribution of the useful signal was between the limits of +15 and +20 microseconds. The signal-noise ratio was about 5. Because rigorous signal-noise differentiation was not achieved, the position of the center of the laser beam was in doubt (the r.m.s. displacement was $\pm 0.5 \times 10^{-6}$ sec and the total error was $\pm 1.3 \times 10^{-6}$ sec); the corresponding error in distance measurement was 200 m.

2. Soviet-French Lunar Ranging Experiments

a. Historical Background of the Project

Cooperation between Soviet and French scientists in the investigation and use of cosmic space was initiated in 1966. The agreement reached by the two countries defined the basic concepts and purposes of some of the joint experiments and established the Council on International Cooperation in the Area of Research and Utilization of Cosmic Space, U.S.S.R. Academy of Sciences ("Interkosmos") and the Centre National d'Études Spatiales (CNES) of France as the coordinating organizations [35].

The French-Soviet lunar laser ranging project was approved in 1967 [35] as one of these joint programs. This move followed: 1) the successful French experiments carried out in 1965, in which laser ranging observations had been made of the American satellite "BOKUN-B", 2) similar observations made in 1967 of the French satellites "DIADEM-1" and "DIADEM-2" (earth satellite distances measured with a precision of 1.5 m) [36], and 3) the USSR 1963 and 1965 experiments described on pages 164-168.

In 1968, scientists from the Lebedev Physics Institute of the U.S.S.R. Academy of Sciences asked French engineers to build a laser reflector which could be set on the surface of the moon. The French agreed to this proposal and set about designing the reflector on the basis of experience gained in designing the reflectors used in the DIADEM satellite observations.

At a meeting held in Paris in October 1968, Soviet scientists checked and approved the French design [38].

The finalized French-Soviet agreement stipulated that the French would provide the USSR with a laser reflector and that the Soviets would provide and orient a dust protector for the reflector [33], the launch vehicle (Luna-17), and the lunar landing apparatus (Lunokhod-1), which would carry the laser reflector. Both countries were to carry out laser-ranging experiments, the French from the Pic-du-Midi Observatory and the Soviets from the Crimean Astrophysical Observatory.

In June 1969, well in advance of the November 1970 launching of Luna-17 and the subsequent landing of Lunokhod-1 in Mare Imbrium on the moon on 6 December at 1900 hrs. U.T., two French reflectors had been received in Moscow [38].

b. Lunokhod-I Experiments. Laser-Ranging Equipment

Information on the technical specifications of the French reflector and the Soviet ground-based observation equipment and the results obtained in the experiments, collected and systematized from several literature sources, are summarized as follows:

1. Moon-Based Reflector

The reflector used in the Soviet lunar ranging experiment was designed and built by French scientists working for the "Aerospatiale" firm and several other cooperating French organizations [35].

The technical characteristics of these reflectors are given in several papers by Soviet scientists and in a paper written by a French scientist, Jacques Husson, which has been partially translated into Russian and published in a Soviet journal [38]. Although the data given in these papers are in general agreement in terms of the major technical and operational characteristics of the reflectors, minor and relatively insignificant differences are reported in the Soviet literature. As of the time this report is written, there is no positive way of determining whether or not the two-reflectors supplied to the Soviets were identical, or whether the discrepancies are due to imprecise editing or "rounded-off" reporting. These variations, including those reported by Husson in describing the equipment used on Lunokhod-I observed from Pic-du-Midi, are noted in the following composite descriptions:

The reflector itself is in the form of a panel whose base and sides are set into a multilayered insulated casing (Fig. 30).

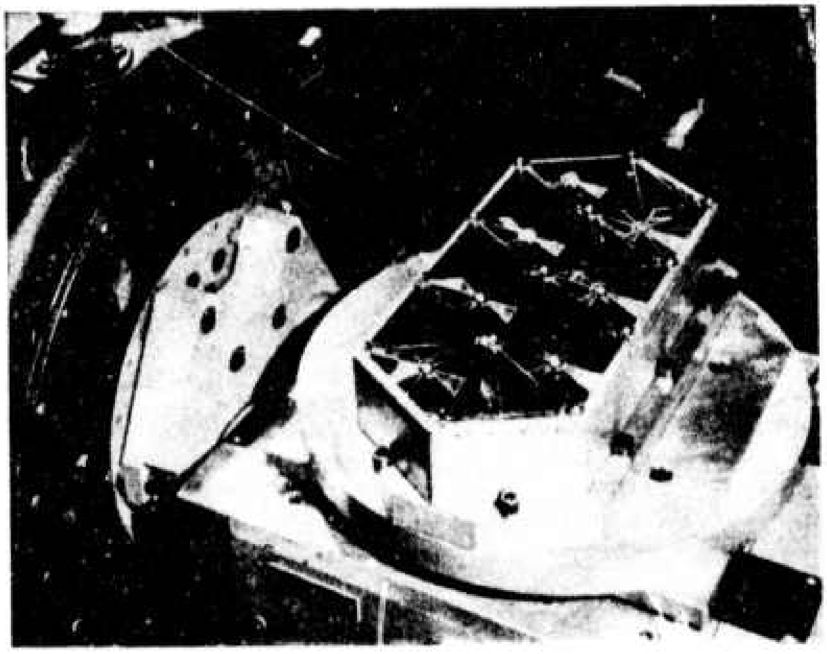

Fig. 30. Photograph of "Lunokhod-1" reflector on test stand.

The technical characteristics of this reflector are:

	As reported by Soviet scientists:	As reported by Husson (Fr.):
<u>Weight</u>	3.8 kg [36] ~3.5 kg [33, 37] 3.7 kg [35]	3.7 kg [38]
<u>Dimensions</u>	45 x 20 x 8 cm [33] 44.8 x 20.4 x 7.5 cm [37, 34] 450 x 210 x 75 mm [36]	44 x 19 cm [38]
<u>Area</u>	640 cm^2 [33, 37]	

The panel consists of 14

"triple" prisms, made of a highly homogeneous silica-base glass possessing high radiation stability and a low coefficient of heat expansion. Rear faces are coated with silver [33, 36, 37].

"trigonal" prisms, made of fused quartz, with faces coated with a thin silver film, protected by a coating of quartz particles [38].

"rectangular prisms, made of artifical silicon; prior to shipment to the USSR, was tested in a high-vacuum thermobarochamber, in which temperatures varied by about 150°. The prisms showed almost no residual deformations even after large drops in temperature [35].

Each of the prisms is a corner reflector cut from a cube. The right angles of the prisms are cut with a precision to 0."2 [34, 37, 36] and the faces, to 0.07 μ [33, 37]. All faces are "metallized" [34, 37]; three (back and side) faces are "metallized" [33].

The reflection pattern for the entire system is ~6."0 wide [33, 37]. The reflector area is 640 cm^2 [34, 37], width, 6."0 [34].

Speranskiy [35] quotes French scientists as claiming that "the optical qualities of their reflectors are three times better than the American reflector set on the moon by Apollo-11" and that "the reflector is expected to be operational for a period of 10 years".

Kokurin [36, p. 38] states that the first measurements carried out by French scientists from Pic-du-Midi were not as precise as the Soviet measurements, i.e., ± 3 m.

2. Ground-Based Laser Ranging Equipment

In the following equipment descriptions, the maximum amount of information was found to be available in a paper by Kokurin et al, published in 1971 [37]. Supplementary data added from other sources, as well as occasionally conflicting information, have been referenced to the appropriate sources.

The laser apparatus used in the "Lunokhod-I" experiment was designed and built at the Lebedev Physics Institute of the USSR Academy of Sciences. It was installed on the ZTSh (Schmidt zenith telescope) 2.6-m telescope [33] (diameter of the principal mirror, F = 42.5 m; field of view, 15') at the Crimean Astrophysical Observatory, USSR Academy of Sciences; the telescope was used to collimate the laser beam, to point the beam at points on the lunar surface and to register reflected laser signals (Fig. 31).

This equipment consists of the following three principal components: A- Laser; installed in telescope focus [33]; B- Apparatus for reflected signal reception and time registration; C- Telescope.

Fig. 31. Laser -ranging equipment installed on the ZTSh-2.6 telescope.

3'. Laser Equipment

The optical schematic of the laser used by USSR scientists in the lunar ranging experiment is illustrated in Fig. 32.

The principal elements are:

Laser transmitter, consisting of the laser L and the amplifier A.

Laser - Q-switched ruby rod, 15 mm in diameter, 240 mm long;

Pump - IFP-5000 flashlamp.

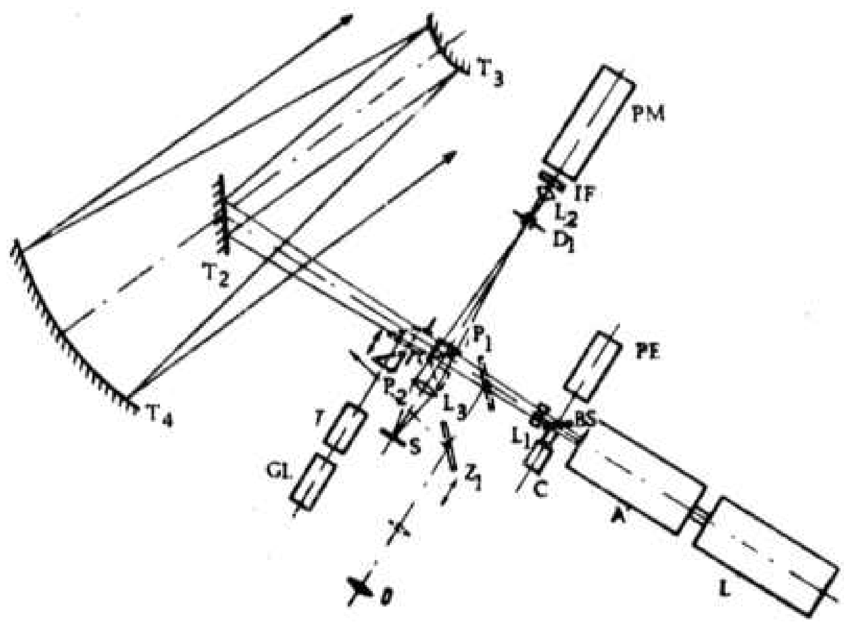

Fig. 32. Optical schematic of the laser-ranging equipment.

The crystal and lamp are enclosed in a hermetic illuminator with a quasielliptical reflector and are cooled by distilled water. Q-switching is effected by a Kerr cell or, in another procedure, by rotating a prism in combination with a KS-19 filter (red) [33].

The photomultiplier PM is of the FEU-77-type (quantum efficiency of 9% [34]; it is tuned by the interference filter IF ($\Delta\lambda$ = 10 Å) and the matching lens L_2. A special prism attachment, which assures multiple passages of light across the photocathode, is used to increase quantum yield. The diaphragm D_1 determines the field of view of the receiver [33].

The reversible prism P is used to switch the equipment from the transmitting to the receiving modes and vice versa [33].

The device identified as the "guide" O, Z_1 is used to point the telescope.

The beam splitter BS assures that a part of the laser energy is shunted to the calorimeter C for measurement and registration of the energy of each pulse and also to the photoelement PE. Pulses from this element are used to synchronize the laser pulse with the triggering of the device used to measure the light signal propagation time.

The lens L serves to match the laser and amplifier to the telescopes T_2, T_3, T_4 in terms of apertures.

The gas laser GL with the collimator T, movable prism P_2, lens L_3 and screen S form an auxiliary system for aligning the entire system as a whole, i.e., integration of the axes and foci of the laser, telescope and photoreceiver. These operations are effected by plane parallel motions and by turning the laser and photoreceiver with the aid of micrometer screws.

The system showing the power supply, control and cooling systems for the laser are given in the following diagram (Fig. 33).

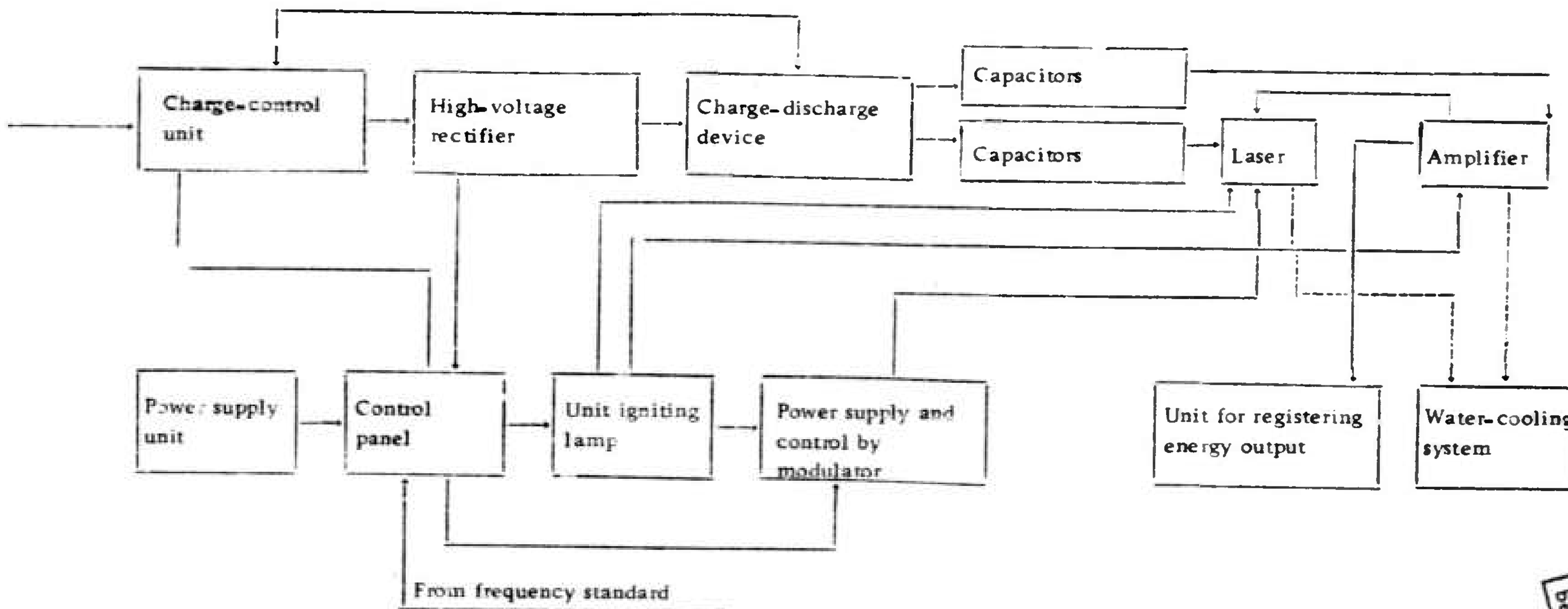

Fig. 33. Diagram for the power supply, control, and cooling of the laser transmitter.

The diagram illustrating reflected-signal registration and measurement of reflected-signal propagation time is given in Figure 34.

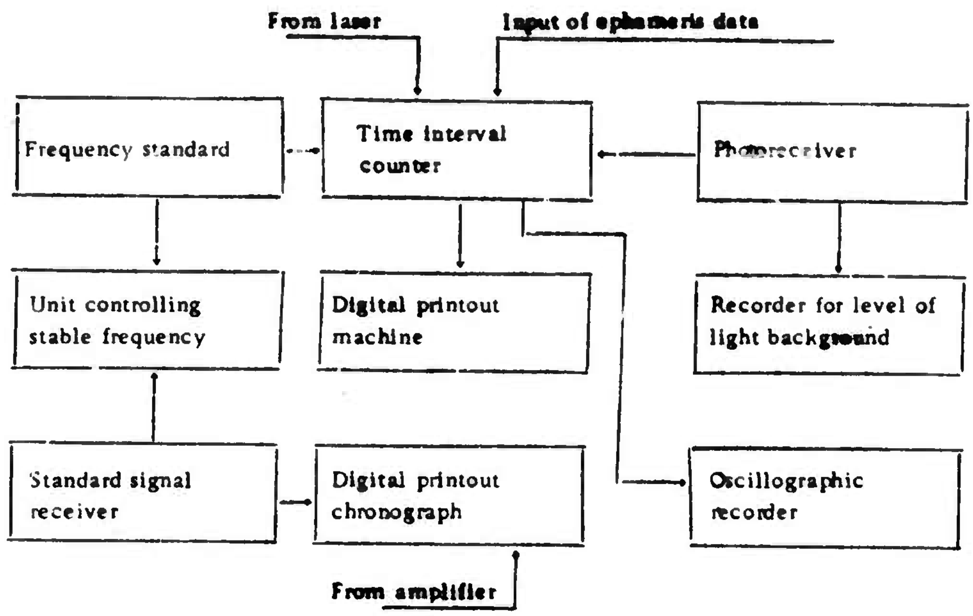

Fig. 34. Diagram of registration apparatus and time interval counter.

The device measuring the time intervals is a decade counter switched on in series. Times of signal propagation are measured by counting the number of frequency standard periods. The measurement device is triggered by the laser pulse, and is stopped by the amplifier pulse. Registration of the stopping device occurs only in the course of a strobe pulse whose center coincides with the calculated time of arrival of the reflected signal. This stopping method also can be used against noise which tends toward loss of the useful signal. In order to avoid such losses, an oscillographic recorder is placed in parallel with the time interval recorder. However, this measurement of time is about one order of magnitude less than that derived with the time interval recorder.

Laser Parameters:

Wavelength, 6943 Å

Energy per pulse, 4 joules

Pulse duration, 2×10^{-8} sec

Pulse repetition rate, 1/15 Hz; (15 sec) [33].

Laser beam diameter, 15 mm.

Telescope (ZTSh) parameters:

Diameter of main mirror, 2.6 m

Focal length of telescope, 42.5 m

Angle of telescope field of view, 15'

Divergence of laser beam leaving telescope, ~5''

Pass band of interference filter, 10 Å

Transmission factor, 0.4

Quantum effectiveness of the photomultiplier, 8-9%

Relative stability of the frequency standard, 10^{-9}

Accuracy of measuring time intervals with recorder, 0 ± 10^{-8} sec

Accuracy of measuring time intervals with oscillographic recorder, $\pm 10^{-7}$ sec

Duration of strobe pulse, 150 μsec [37]; 20-150 μsec [34].

Pointing the Telescope

The French reflector retains its operational qualities only during lunar night conditions, its effectiveness decreasing under the influence of solar heat. Since it is difficult to point the telescope on a reflector in a dark area of the moon, a reference point (crater) whose coordinates are known is selected from the lighted side. The telescope guide is pointed on this point. In order to point the telescope, along whose axis the laser beam passes, on the reflector, the guide and telescope must be set at an angle equal to the angular distance between the reflector and the reference point.

Since, in this scheme, the use of a separate guide is not admissible because of poorly controlled differential deformation of the guide-telescope system, the guiding operation must be carried out by observing the reference point in the field of view of the telescope itself, in which the focus of the laser is also located. This requires an adequately wide field of view in order that the reflector-reference point base can be fitted in. These conditions are met only by the prime focus or a Cassegrain focus; however, placement of the apparatus in these foci has serious drawbacks since they move with the telescope tube.

An unconventional place was selected for setting up the apparatus - the center of the polar platform. This shortens the Coudé focus but eliminates two of the main drawbacks of the classical Coudé focus i.e., the small field of view and its rotation relative to the astronomical system of coordinates (α, δ) when the telescope is turned. A coordinate grid consisting of two mutually-perpendicular rules (x, y) is set in the focal plane. The apparent guide is moved along these rules by means of micrometer screws. The reading accuracy of the relative position of the guide and laser focus is of the order of 0.1 mm or $0''.5$. The rule scales and their positions (angles) relative to the astronomic grid (α, δ) are calibrated from star pairs before the observation session begins.

Measurement Results

The technical data of the reflector, as well as the energy and spectral characteristics of the ground apparatus, required that measurements be made only during conditions of Earth and lunar night. Further, the moon had to be high above the horizon (zenith distance $\leq 60^{\circ}$) to reduce the absorption and scattering of the laser signal in the atmosphere.

These conditions existed on 5-8 December 1970 during the first lunar night after "Luna-17" landed on the moon. During this period there were two measurement sessions, on 5 and 6 December. Poor weather conditions prevented observations on 7 and 8 December.

The dashed lines of Fig. 35 show the oriented shape and dimensions of the lunar area covered by the transmitted laser beam.

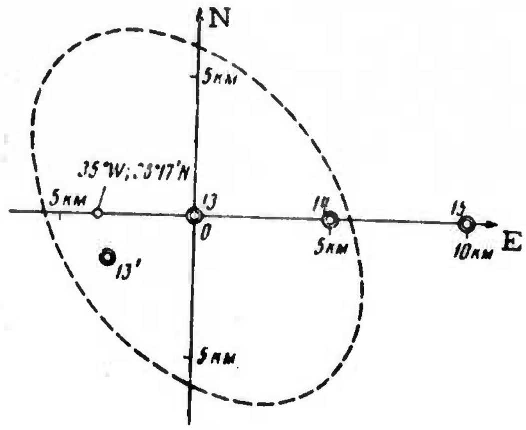

Fig. 35. Sketch of a portion of the lunar surface. The double circle symbols denote the positions of the laser spots.

The program of search for the reflector included successive bombardment of 25 points equally distributed in a 25 x 25 km square, beginning from the center point whose coordinates were 34°53' W and 38°17' N (point no. 13 in the figure). This location was determined in the course of the 5 December session, which lasted 40 min (170 pulses). The reflected signal was clear enough but was not as clear as had been calculated *a priori*.

During the 6 December session, the laser beam was directed successively toward points 13', 14 and 15, each being bombarded over a one-hour period (250 pulses per point). Signals received from point no. 13' were approximately of the same magnitudes as those received from point no. 13. The signals from point no. 14 were very faint and the signals received from point no. 15 were almost nonexistent. Points north, west and south of point no. 13 were not tracked because of the short observation periods.

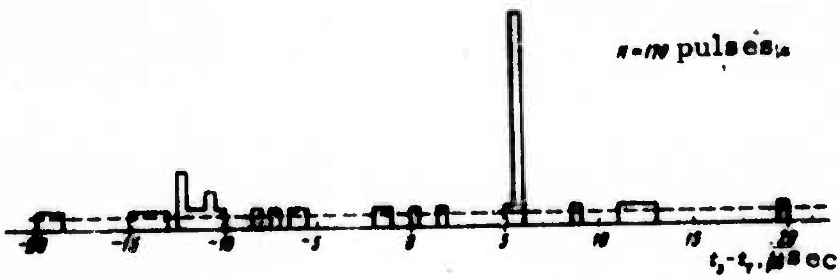

Fig. 36. Histogram of the 5 December ranging period.

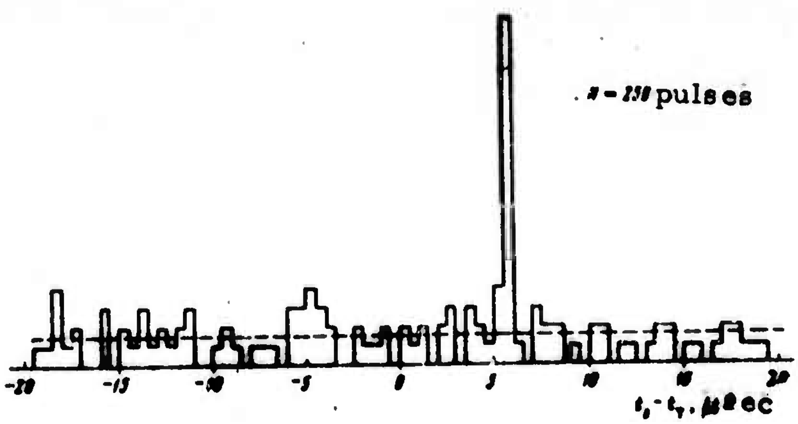

Fig. 37. Histogram of the 6 December ranging period.

Histograms (Figures 36 and 37) were constructed, which showed the magnitudes $t_i - t_T$ (t_i = readings of the time-interval measurement device or of the oscillographic registration; t_T = theoretically calculated time of signal propagation to and from the reflector), to make preliminary identifications of the reflected signal. These histograms show only part of the strobe pulse (intervals of ± 20 μsec on either side of the center) and the peaks of the reflected signals were shifted 5-6 μsec away from the calculated positions.

Sectors of the strobe pulses corresponding to the reflected signals were analyzed separately to make the final identifications of the signal points and to investigate changes in time in the measured distances. All pulses registered by the photomultiplier, including noise, are shown in Figures 38 and 39 as a function of time (i. e., the number of laser pulses). The signal points in both instances are grouped in intervals ~ 0.3 μsec wide and show a smooth time change during the observation session. Assuming that the signal was 0.3 μsec wide, the signal-noise ratio obtained for the 5 December session is of the order of 27 and ~ 21 for the 6 December session (point no. 13'). The average background noise is shown by horizontal dashed lines in the histograms (Figs. 36 and 37).

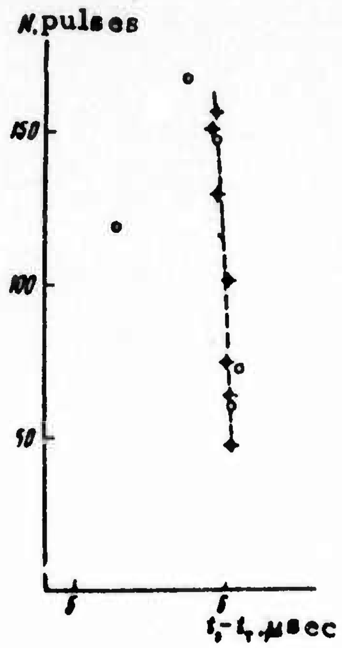

Fig. 38. Distribution of signal points during the 5 December observations.

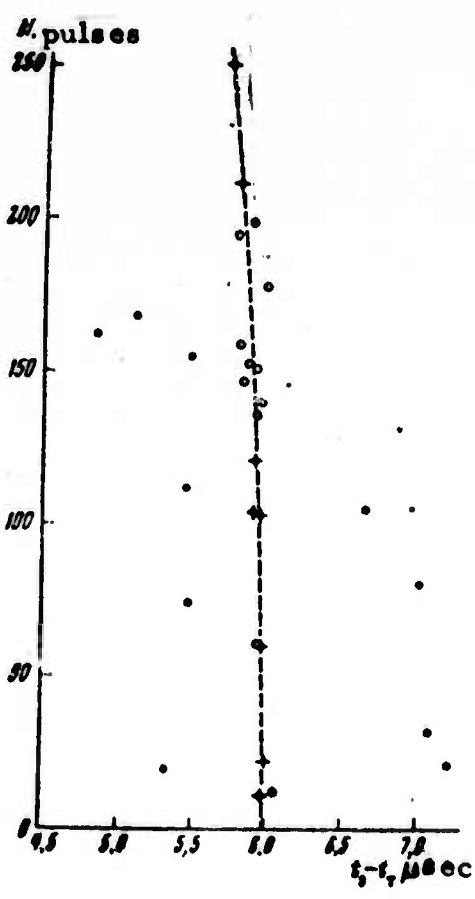

Fig. 39. Distribution of signals points during the 6 December observations.

Distances to the reflector were determined only from signal points determined with the time interval measuring device (decade counter) with a precision of $\pm 10^{-8}$ sec, shown in the figures by a cross +. By approximating the changes in these points during the observation sessions by a smooth curve, the deviations of the experimental points from these curves did not exceed $\pm 2 \times 10^{-8}$ sec, i.e., were compatible with the apparatus errors and corresponded to a distance error of $\pm$ 3 m.

In calculating the level of the reflected signal, it was assumed that the energy of the laser pulse was 4 joules; the area of the reflector, 640 cm^2; the area of the telescope, 5.3 m^2; the transmitter wavelength, 6943 Å; the distance to the moon, 380,000 km; the divergence of the laser beam beyond the atmosphere, about 10"; the width of the reflector pattern, about 6"; the coefficient of signal loss due to aberration rate, about 0.6; the coefficient of loss in the transmitting equipment, about 0.6; the coefficient of loss in the receiving equipment, about 0.25; the quantum output of the photomultiplier, 0.08; the coefficient of reflection of the reflector, about 0.9; the transmissibility of the atmosphere, about 0.7, for a net loss of about half of the reflected signal.

These calculations showed that the experimental value of the level of the reflected signal obtained for point no. 13 was 0.065 and 0.076 for point no. 13', i.e., almost one order of magnitude smaller than the calculated signal. However, the calculations were very approximate because the search program was not carried to completion and was not verified by a precise pointing of the telescope on the reflector. Furthermore, during the measurement period the atmosphere was extremely turbulent and because of this, estimates made with the widened laser beams could not be accepted as completely correct.

c. "Lunokhod"-2 Experiment.

"Lunokhod-2", launched by "Luna-21", landed on the moon at 0135 hrs Moscow time, 16 January 1973. The position given for the landing site is $30^{\circ}27'$ E. Long. and $25^{\circ}51'$ N. Lat. in the LeMonnier crater (55 km in diameter) near the eastern edge of Mare Serenitatis [39, 40].

Information on the route followed by "Lunokhod-2", the onboard scientific apparatus, the scientific experiments carried out to and from it, and the results obtained in these experiments, is still unavailable except in the most general form and is found, with one exception, only in newspapers and semipopular journals. This single exception is a scientific paper authored by American, French and Soviet space scientists, published by the French Academy of Sciences. As is usual in the ever-increasing number of such cases, these jointly prepared papers offer little basis for identification or evaluation of specific Soviet contributions to the project. Obviously, the individual contributors are the best sources of such information.

Reported Scientific Programs. General Results.

In addition to the physical- and geophysical-type programs executed from "Lunokhod-2", which have generally been accorded greater emphasis in the press releases than have the mapping and geodetic programs (regolith bearing strength and chemical properties, magnetic fields, solar and galactic corpuscular radiation, lunar sky luminosity in the visible and UV ranges), the mapping and geodetic programs involved: 1) the televised transmission of 86 panoramas and more than 80,000 telephotos of the lunar surface, with stereoscopic images provided for the most interesting topographic features; and 2) experiments in laser ranging of "Lunokhod-2" [40], carried out in accordance with the USSR-France and other international space research agreements.

Essentially identical sketch maps, showing a part of the route followed by "Lunokhod-2" from its landing site to three sites at which the vehicle stopped to make observations, are given in [39] and [41] (see Fig. 40). A TASS report [40] states that for five lunar days, the relief was rugged and "Lunokhod-2" covered a distance of 37 km and that "its improved maneuverability and mobility made it possible to cover a distance 3.5 times that traversed by "Lunokhod-1".

Geodetic laser instruments aboard "Lunokhod-2" consisted of the following:

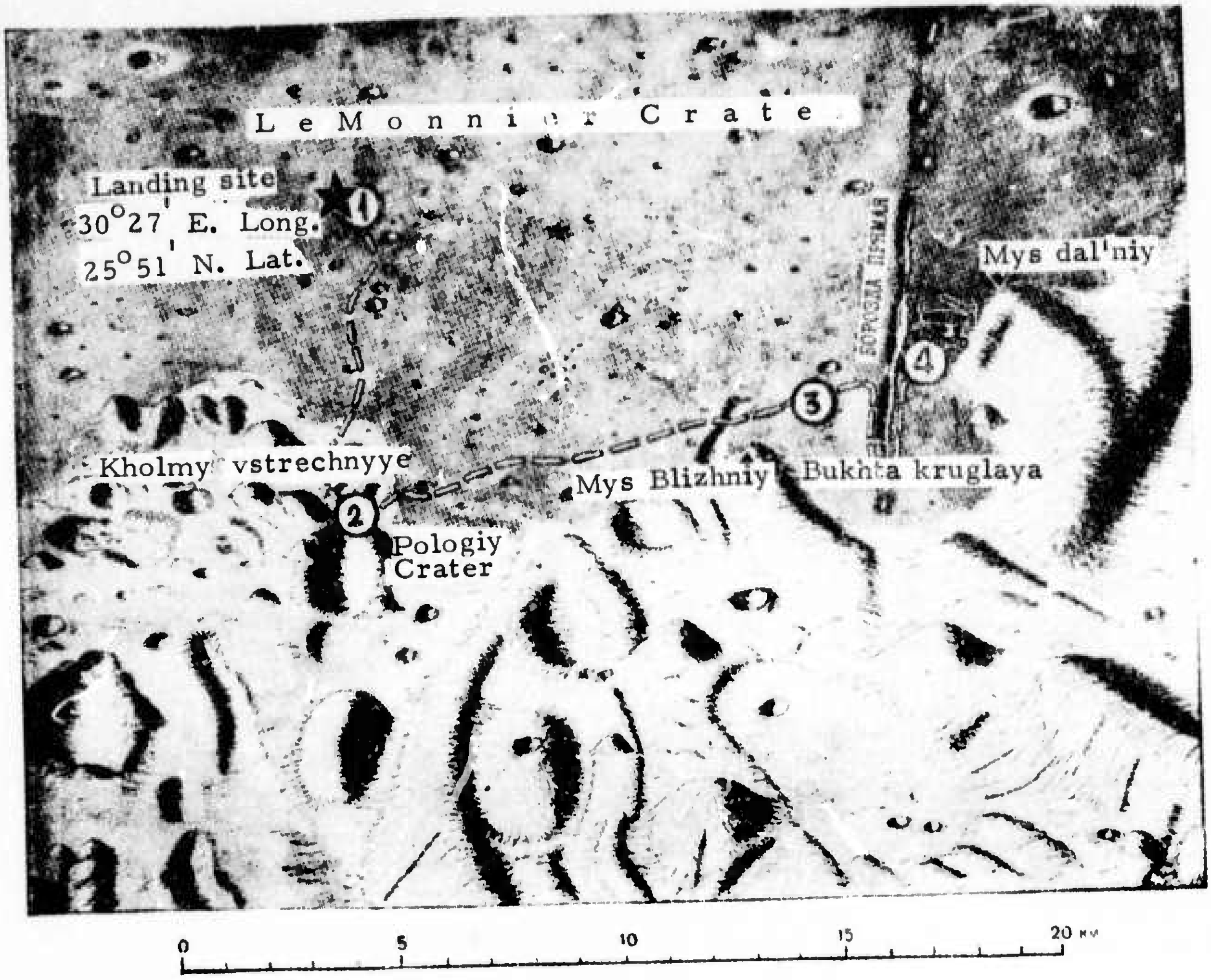

Fig. 40. Sketch showing route of "Lunokhod-2" on the lunar surface.

1) corner reflector manufactured in France [39, 40, 41, 43]

2) "Rubin-1" photoreceiver [39, 40, 41].

Data available in the literature on the times and positions at which laser ranging observations were made to the corner reflector on "Lunokhod-2" are inexact and incomplete. These data range from the statement in [42] that "the vehicle was set in the position required for carrying out laser ranging experiments during the final days of the first lunar day following the Lunokhod-2 landing", to a more "detailed" description given in [39], which states that regular laser-ranging measurements of distances to the reflector were begun in June 1973 by the Physics Institute of the USSR Academy of Sciences using the 2.6 -m telescope at the Crimean Astrophysical Observatory, and that [at the time of the press release of 20 November 1973] observation sessions (2-4 measurements per month) were still being held.

According to [39], these measurements involve the transmission of powerful laser pulses of durations of the order of 10^{-8} seconds through the telescope, forming the pulses into a very narrow beam whose loss in signal strength over the earth-lunar reflector-earth path is of the order of 10^{19}-10^{20}. The distance to the reflector is determined in accordance with the laser pulse propagation time. The accuracy of the measurement of the time interval is given as 10^{-8} sec. Each measurement represents a separate series consisting of several hundreds of light pulses propagated at 3-sec intervals. The statistical precision of determinations of distances to the lunar reflector is reported as being $\pm$ 40 cm.

The "Rubin-1" photoreceiver installed on "Lunokhod-2" has repeatedly received laser beams propagated from ground observatories. According to Gurshteyn [41], readings of laser beam directions combined with lunar disk photographs, made adequate checking of "Lunokhod-2" stopping positions possible.

Other laser ranging experiments apparently were carried out at "several other observatories" [40]. Vinogradov and Sokolov [39] report the use of laser equipment installed at the Vysokogornaya Observatoriya of the Shternberg State Astronomic Institute in the Zailiyskiy Alatau Mountains near Alma-Ata and "other stations in the Soviet Union". They also report that these observatories were in constant optical contact with "Lunokhod-2", accurately determining its selenographic coordinates from more than 400 receptions of laser rays by the "Rubin-1" receiver and from more than 1500 photographs of the moon.

This report also gives some general information on the optics of the telescopes used to transmit laser beams to the moon. First, these optics narrowed the laser beam to several angular seconds. Secondly, a special mechanism [not described] was used so that the laser beam made a spiral scan of the crater. Thirdly, the direction of each laser pulse was registered on film simultaneously with the "photoregistration" of the moon, and fourthly an angular reflector, set in the telescope tube, which returned a small part of the radiation in the telescope rigorously parallel to the axis of the propagated pulse, was used to determine beam direction. When the laser beam reached the "Rubin-1" photoreceiver, a portion of pulse energy was converted into electrical energy, and r-f "acknowledgement" of beam incidence was transmitted to the earth.

A preliminary report prepared by scientists from several nations (including Kokurin and Abalakin of the Soviet Union) dealing with the first laser reflections obtained from "Lunokhod-2" [43], states that two series of measurements of reflected laser signals propagated with a ruby laser installed on the 2.7-m telescope at the MacDonald Observatory were made on 25 January 1973. In each series of measurements, the laser beam was radiated in 3-sec bursts of 3-joule energy pulses, lasting for 4 nanoseconds. The authors state that signal intensities were comparable to those received from the Apollo-15 reflector and that the time required for beam passages over the station-reflector distance corresponded to the nominal values of reflector coordinates.

C. Recent USSR Developments in Laser Beam Modulation Techniques as Applied to D. M. E.

Information circulated during the IUGG- and COSPAR-sponsored International Workshop on the Use of Artificial Satellites for Geodesy and Geodynamics, held in Athens, Greece, on 14-21 May 1973, indicated that Soviet scientists and technicians might have scored a significant breakthrough in laser geodetic instrumentation, specifically in laser-beam modulation techniques, which might yield significant improvements in high-precision distance measurements, i.e., better than 30-50 cm.

Normally, Soviet publication policies, especially those relating to data of a potentially sensitive nature, call either for delayed publication (beyond normal publication lag) or for long-term or total suppression of publication and external distribution of important scientific and technical information. This policy has prevailed throughout the entire period of Soviet control and has applied to many scientific disciplines, publication restrictions on USSR geodetic instrumentation and control data being prime examples of the rigid constraints imposed by these policies. As mentioned elsewhere in this report, these restrictions occasionally have been lifted for short periods of time for reasons best known to Soviet policy makers, although possible reasons might be pride of accomplishment and desire for world recognition. Such a temporary easing of publication policies occurred during the period immediately following the launching of the first Soviet satellite.

Because of the unavailability in 1973 of the abstracts for or copies of the papers presented at the Athens Workshop, and on the assumption that a temporary easing of Soviet publication policy might recur in relation to rumored advancement in laser-modulated geodetic instruments, an examination has been made of the recent Soviet scientific and technical literature (geodetic, astronomic, physical and electronic) and of newspapers to ascertain the type and amount of information that has been released on laser beam modulation as related to geodetic instrumentation and measurements. This survey reveals that relatively few papers have been published in this field, and that none of those available at the time this report is being written specifically relates laser-beam modulation techniques to Soviet satellite laser geodesy. With the exception of two reports, all of these papers refer to conventional ground geodetic measurements and instrumentation of the electronic distance-measuring type (d.m.e). Of these exceptions, one (Movsesyan et al [44]) specifically mentions applicability to satellite observations and the second (Zherbina, Zinchenko and Petrov [50]) described a wind-tunnel modelling experiment devised to investigate the image quality of an "artificial star" subjected to varying degrees of atmospheric turbulence.

One of the earliest papers published on the modulation of laser d.m.e. was submitted for publication in 1966 by Zalesskiy et al, but was not published until 1967 [45]. The purpose of this paper was to determine the modulation characteristics of semiconductor sources of recombination radiation, in particular, to determine the maximum attainable percent of light modulation at frequencies greater than 1 GHz, using an ordinary FEU-28 photomultiplier. Here, the source was a GaAs injection diode excited by pulsed currents lasting from 0.2-1.0 μsec. A GS-15 generator with a current booster was used to generate the pulses. Pulses lasting 5 μsec with SHF load at a resonance frequency of $\omega_c/2\pi \sim 1$ GHz and pulse levels of up to 25 w were fed simultaneously from the diode, with the result that the light flashes consisted of two components - a steady-state and an SHF combination. Heterodyning was accomplished with standard issue G3-21 and G4-31 instruments, in which anode isolation in the generator tubes had been improved. The results of the experiment indicate that the procedure provided an easy method of measuring the coefficient of light modulation in the SHF range with the heterodyne placed at the photomultiplier output.

In 1972, Dianova et at [46], utilizing information obtained by K. Marks of the Yerevan Polytechnical Institute on the modulation characteristics of $LiNbO_3$ crystals, cite the papers published by Movsesyan and others in journals that appear to be unavailable in the USA, as well as those by Blumenthal and Megla, published in the Proceedings of the IEEE in 1962 and 1966. The Dianova paper gives the results of experiments in which these crystals were used to modulate and demodulate He-Ne laser radiation and lists the following advantages of these crystals over those of the ADP and KDP crystals used in such d. m. e. as Geodimeters and Mekometers; i. e., with $LiNbO_3$ crystals, at frequencies close to 500 MHz and a toroidal-type modulator: 1) the power required to obtain identical modulator effectiveness is reduced by a factor of 2-2.5 with the $LiNbO_3$ crystal; 2) modulator capacity is reduced by a factor of 4; 3) the $LiNbO_3$ crystal is non-hygroscopic and has greater stability, and 4) no thermal effects occur at an average 6-w power. Disadvantages accruing from the use of these crystals include: 1) a possible 25% reflection from the crystal face caused by its large angle of refraction, but which can be reduced by coating the crystal, and 2) the development of a residual light flux at the analyzer output, caused by elliptical polarization occurring when plane polarized light is transmitted through the crystal. The authors anticipate that this disadvantage will be overcome with improved crystal manufacture.

The system described by Movsesyan et al [44] is described as "unique" because the modulator ($LiNbO_3$ crystal) and the demodulator (photomultiplier) have been combined in the resonator as shown in Fig. 41.

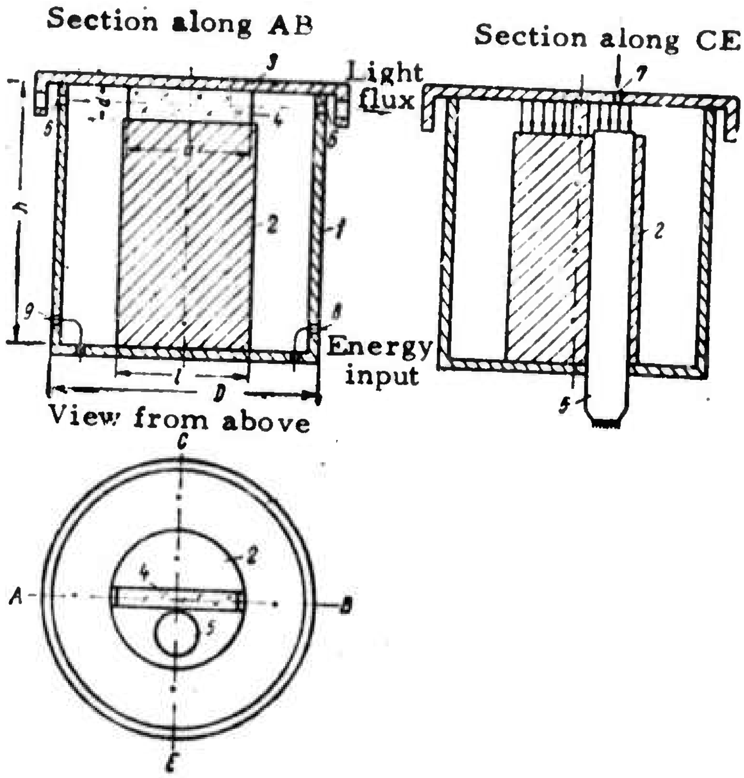

Fig. 41. Resonator with combined modulator and demodulator.

1- cavity resonator; at a 458 MHz frequency, dimensions = 70 mm, D = 100 mm, h = 68 mm. Crystal length = 30 mm; crystal thickness, 3 mm; 2- coaxial unit; 3- cover cap; 4- $LiNbO_3$ crystal; 5- photomultiplier, inserted in hole in 2; 6- aperture, through which the light flux from the source passes through 4 in a direction perpendicular to the force lines of the electrical field; 7- aperture, through which the reflected light flux is transmitted along the force lines and perpendicular to the plane of the photocathode; 8- coupling loop to supply energy to resonator; 9- loop to control resonance.

As Fig. 42 shows, the plane-polarized beam from a LG-55 laser is transmitted to the crystal and analyzer and to the reflector. The reflected

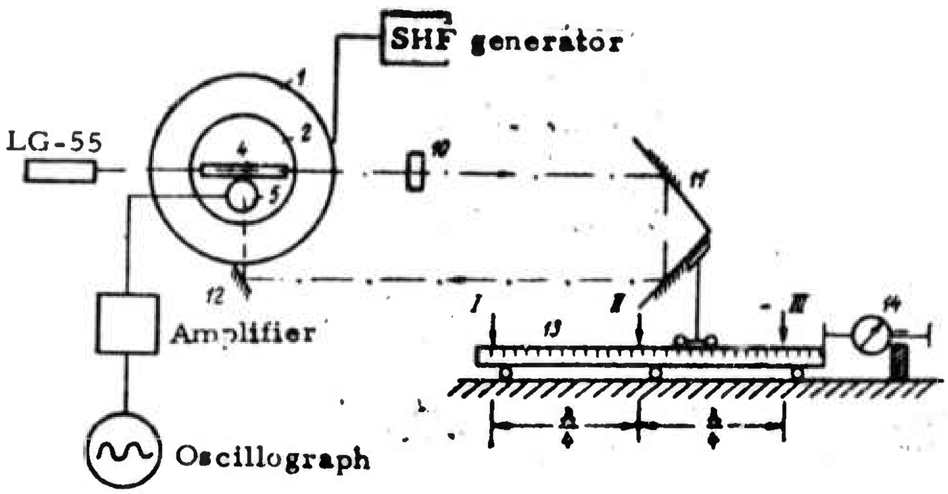

Fig. 42. Schematic showing laser beam path measurement.

10- analyzer; 11- reflector, set on 2-way carriage; 12- mirror, mounted on two-way carriage; 13- scale, 38 cm long; 14- dial-type micrometer (run = 50 mm; divisions = 10 μm);
(Other unit designations are the same as in Fig. 41).

beam then is transmitted to the amplifier by means of a mirror and the signal gain is observed on the oscillograph. Repeated measurements made with this system showed that the demodulation, effected because of the presence of an electrical field in the resonator, occurs at twice the modulation frequency. The effect produced in the photomultiplier by the electrical and light fluctuations is that the magnitude of the photocurrent depends on the phase difference between the reference (electrical) signal and the received signal. Data obtained from repeated determinations of minima positions by the extremum method (micrometer readings to the left and right of minimum point), and of the signals registered on the oscillograph after amplification, demonstrate that this device is very sensitive and is suitable for use in high-precision d. m. e.

Prilepin and Golubev [47], in direct application to measurements of distances, present a design for a new laser-ranging instrument having a modulated carrier frequency and optical heterodyning in the photoreceiver, and also discuss a distance measurement method which utilizes these effects. The general schematic for this instrument is given in the following figure (Fig. 43).

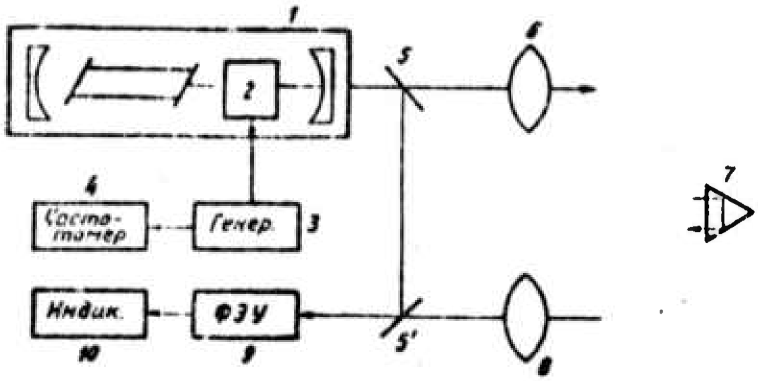

Fig. 43. Schematic of a laser d. m. e.

1- laser resonator; 2- electrooptical crystal; 3- generator supplying alternating sinusoidal voltage to 2; 4- frequency-measuring device; 5- beam splitter, 6- optical system; 7- reflector; 8- optical system receiver, which picks up reflected light flux that is directed to 9; 9- photomultiplier, which also receives the second part of the laser beam over a short optical path (5-5'). The frequency difference in the two signals, after amplification (amplifier not shown in diagram) is fed to 10- indicator, from which the time when the frequency difference tends to zero can be determined.

A measurement method, proposed for use with this type of d. m. e., is illustrated by a numerical example, in which the difference between the two laser frequencies was 80 MHz. The results obtained were found to be "100 times better than those obtained with presently [1972] used equipment and methods". The most important disadvantage, acknowledged by the authors, was the necessity for precise spatial matching of the signal and heterodyne wave fronts.

Late in 1972, Galutin, Zenkevich and Skibarko [48], recognizing that frequency-modulated gas laser beams offer greater possibilities than do pulsed laser beams for higher resolution and precision in laser-ranged distance measurements, investigated the multimodal operation of a He-Ne laser* for these purposes. The experiments showed that a "jump" effect variation in the mean frequency of the output signal of the frequency-modulated laser d.m.e. occurred with a change in the distance measured, that this "jump" effect was associated with radiation quasiperiodicity, and that with a frequency-modulated laser d.m.e., distance can not be measured more precisely than one-half the resonator length.

Pointing out the desirability of producing small high-precision d.m.e. capable of rapidly measuring distances ranging from hundreds of meters to several km with errors of less than 1 mm, and admitting that "such d.m.e. do not yet exist, although sophisticated experimental high-precision d.m.e. have given distance-measurement errors of about 0.02 mm

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* $\lambda = 0.63\ \mu$; frequency deviations caused by resonator design limited by Doppler-widened line, the spread above the maximum being about 1700 MHz at the 0.5 intensity level, making a frequency deviation of the order of 500 MHz permissible without noticeable amplitude modulation.

over a distance of 34 cm"*, K. A. Gulgazaryan [49], describes and gives the test results obtained with a d. m. e. which uses an externally-modulated gas [unspecified] laser. This d. m. e. is designed so that the upper limit of the radiation modulation frequency is dictated by a special photoreceiver, in which the signal and reference photomultipliers operate under identical conditions.

The schematic for this gas laser d. m. e. is given in Fig. 44, below.

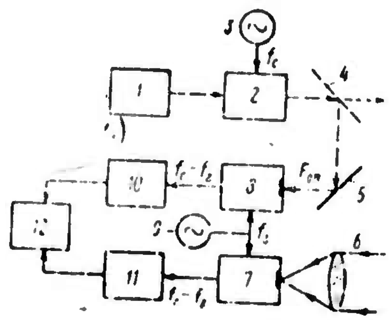

Fig. 44. Schematic for gas laser d. m. e.

1 - gas laser; 2 - modulator; 3 - generator (GSS-12 type); 4, 5 - mirrors; 6 - objective; 7 - signal (FEU 28-type) photomultiplier; 8 - reference (FEU 28 - type) photomultiplier; 9 - SHF heterodyne; 10 - amplifier; 11 - amplifier; 12 - phase meter.

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* Adrianova, I. I., Z. V. Nesterova, Yu. V. Popov. Optiko-mekhanicheskaya promyshlennost', no. 10. 1969.

The photoreceiver in this d.m.e. is designed so that the output cascade of the heterodyne is located between two photomultipliers (see Fig. 45 below).

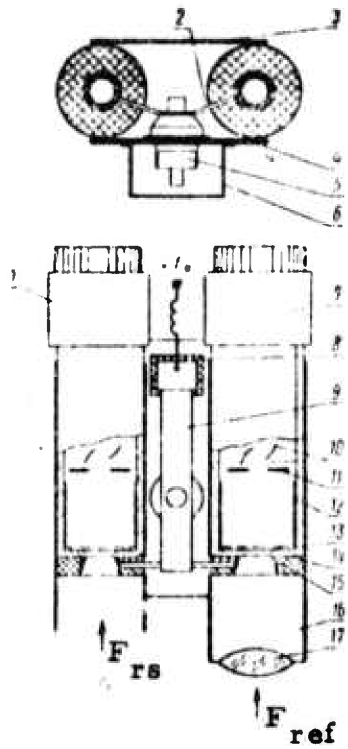

Fig. 45. 1- reference photomultiplier (FEU-28-type) encased in metal tube; 2- voltage connection; 3- shield; 4- ground plate; 5- GS-4V-type triode; 6- shield; 7- signal photomultiplier; 8- dialectric; 9- metal strip (with 4 forms quarter-wave cavity resonator); 10- multiplying circuit; 11- diaphragm; 12- cathode cylinder; 13- semitransparent photocathode; 14- dielectric; 15- external electrode; 16- metal tubes; 17- lens; F_{rs} - reflection from target radiation (signal); F_{ref} = reference radiation.

In a laboratory investigation of this device, a semiconductor injection diode, modulated by a GSS-12-type generator (~500 MHz frequency), was used as the light signal source. The diode was located at the antinodal point of a quarter-wave coaxial resonator. An additional dc current (~200 mA) was supplied to the diode to shift operation points. Part of the diode radiation was focused directly on the center of the reference photo-multiplier cathode and the remaining part, after reflection from a target located about 30 cm from the receiver, was focused on the signal photo-multiplier. SHF loads of about 50 v on the external electrodes were measured with VK 7-9 voltmeters.

The results of this experiment showed that the total error in phase difference measurement was about 1°, corresponding to a distance measurement of approximately 0.8 mm, and that even with the lowest-power lasers commercially distributed in the Soviet Union, utilization of the described equipment, would permit d.m.e.-ranged distances of "not less than several kilometers".

Over a period of the last few years (1967 - present), the Soviet scientific literature has contained an increasing number of papers dealing with the effects of atmospheric conditions on optical image quality. With the advent of lasers, investigations of this type have been intensified and many papers on the effects of atmospheric turbulence, clouds and fog on laser beam propagation have been published in the geodetic, physics, electronic, and astronomical literature. Two of the most recent of these papers contain the results obtained in precisely-controlled laboratory and field investigations of the effects of atmospheric turbulence on laser beam propagation as they relate to distance measurements.

The first paper, written in 1971 by Zherbina, Zinchenko and Petrov [50], was published in 1973 in an astronomical journal and contains a description of the equipment used and the results obtained in a modelling experiment designed to investigate the image quality of an "artificial star" as affected by the passage of light through a turbulent atmospheric layer. The equipment consisted of a light source (OKG-11 He-Ne laser), IAB-451 schlieren instrument, a wind tunnel and registration equipment (photoelectric scanner of a FEU-79 photomultiplier). Air flow rates used in the wind tunnel were 0, 6, 13, and 23 m/sec. Heat was supplied by a special heater. The use of electrical and optical systems made registration of two-three diffraction maxima possible. Investigations were made of the dependence of the magnitude of irradiation of the first minimum on the thickness of the turbulent layer and at three maximum temperatures in the layer; the influence on image quality of layer thickness and the maximum temperature in the layer at various stages of diffraction pattern decay; the influence of air-flow speed on irradiation of the first minimum in the presence of temperature inhomogeneities; and the influence on image quality exerted by a spherical dome with cylindrical sides, installed in the wind tunnel.

The results showed that for the short distances involved in the wind tunnel and for the small phase changes that are characteristic of light turbulence, the structure parameters C_n^2 of the refractive index were of the same order of magnitude, i.e., the quality of the image of an artificial star depended on the path of the light wave in a turbulent atmosphere and on the intensity of turbulent fluctuations of the index of refraction.

Intensive turbulence of the order of $C_n^2 = 1 \times 10^{-12}\ m^{-1/3}$ had to be created in the tunnel in order to produce even slight image decay, as against conditions in the atmosphere where light turbulence is of the order of $C_n^2 = 1 \times 10^{-16}\ m^{-2/3}$ and strong turbulence is of the order of $C_n^2 = 1 \times 10^{-13}\ m^{-2/3}$. Since only small differences were found for the length parameter C_n^2 L, both in the atmosphere and in the tunnel, the modelling results could be substituted into the field results without experimenting with images of small angular dimensions, and the magnitude C_n^2 = const could be used as a dimensionless number in wind-tunnel modelling of the effects of the atmosphere on star image quality. The value $C_n^2 L = 6 \times 10^{-13}$ could be taken as the critical value of good image quality.

The second of these papers was written in May 1972 by A. I. Vereshchaka, Yu. V. Popov and V. P. Smirnov and published in January 1973 [51]. This paper is of particular interest because it contains a schematic of a high-precision CO_2 laser d. m. e., a description of its operational principles and procedures, as well as the results of field investigations carried out with this equipment under adverse weather conditions.

The fact that, like Gulgazaryan in [49], described earlier in this section of the report, the authors of this paper cite the work by I. I. Adrianova et al, in describing the principal design features of the d. m. e., and the similarity of the two design schematics, indicates that the design of the CO_2 laser d. m. e. (Fig. 46) could represent

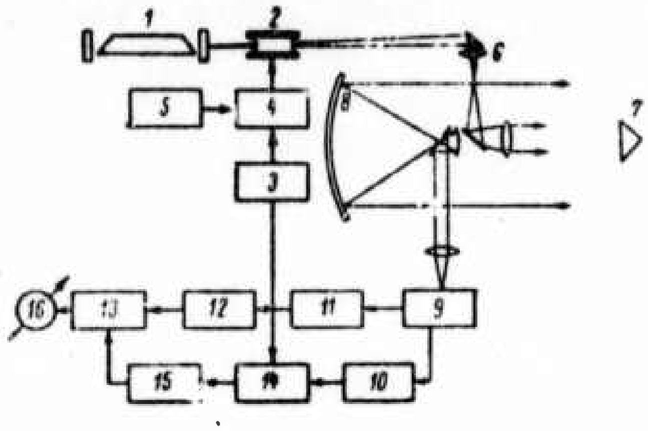

Fig. 46. CO_2 laser d.m.e. schematic.

1- CO_2 laser (commercially manufactured OKG-15); wavelength, 10.6 μm; 1 w output in single-mode regime; 2- Modulator; modulating frequency, 5 MHz; gallium arsenide crystal; operates at quarter-wave d.c. voltage bias from 5; 3- High-frequency generator, frequency-stabilized by quartz through filter 4; 4- Filter; 5- Source of d.c. bias; 6- Transmitting optics; 7- Reflector; 8- Receiving optics; ternary Cd-Hg telluride photoresistor operating at the temperature of liquid nitrogen; 9- Photoreceiver; 10- High frequency generator (heterodyne); supplies 5.25 MHz quartz-stabilized a.c. current to photoresistor 11- Amplifier of IF signal channel with automatic gain control; 12- Beam splitter; 13- Phase detector sensor; 14- Mixer; 15- Amplifier of IF reference channel signal.

a modification of the experimental high-precision, externally-modulated gas laser d.m.e. described by Gulgazaryan as having given "experimental distance-measurement results of ~0.02 mm over a distance of 34 cm".

Field tests were carried out on a premeasured base line by setting up the reflector at intervals along a base line known to be within phase cycle limits (30 m) as shown in the following diagram (Fig. 47). These data show that the error of a single measurement did not exceed $\pm$ 10 cm ($\sim 1^{\circ}$).

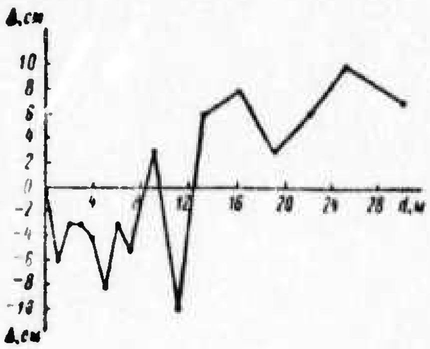

Fig. 47. Distance measurement error within the limits of a phase cycle.

In another test, single measurements, made over a premeasured 300-m line, showed that the r.m.s. error "did not exceed the errors obtained in laboratory tests. Evaluation of the energy capacity indicated that, with a 30 cm^2 reflector, this d.m.e. can be used to measure distances of not less than 10 km during adverse weather conditions".

D. USSR Stations at Which Laser-Ranging Equipment Has Been Installed.

1. Crimean Astrophysical Observatory (Simeiz)
2. Uzhgorod
3. Zvenigorod
4. Vysokogornaya Observatory of the Shternberg State Astronomical Institute in the Zailiyskiy Alatau Mountains near Alma-Ata.

The first three stations operate in close cooperation with the Czechoslovakian laser station at Ondrejov.

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PART VI

SOVIET LONG-BASE LINE INTERFEROMETRY*

A. USSR Intracontinental Long-Base Line Interferometry.

According to [6], the Soviet radio astronomers N. S. Kartashov, G. B. Sholomitskiy and L. I. Matveyenko, in 1963 proposed a method of "extra-long-base" radiointerferometry, with which almost any angular resolution could be obtained. This proposal recommended the separate reception of signals, simultaneous signal and time registrations (atomic hydrogen frequency standard) on magnetic tape, and computerized data processing.

Professor V. S. Troitskiy of Gor'kiy University, [9], claims that about 1965, the USA, Canada and the USSR began to develop interferometers with separate receptions based on the registration of signals at each station and on subsequent data processing. That Soviet scientists were aware of and interested in the developments being made in interferometry by Western scientists is clearly demonstrated in a 1965 paper by L. I. Matveyenko, N. S. Kardashchev, and G. B. Sholomitskiy of the Lebedev

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* Note: The information summarized and systematized in this chapter was collected only as a by-product of a search made of the recent (1970-1973) literature to obtain Soviet satellite geodesy data. No attempt has been made to prepare an up-to-date and complete state-of-the-art report on this subject.

Physics Institute of the USSR Academy of Sciences [11]. In this report, the authors cite eight references, seven of which were written by western scientists (1954-1963)*, relating to the use of independent heterodynes and signal registrations and of high-speed data processing methods. Troitskiy also states that the USSR agency developing these interferometers was the Scientific Research Radiophysics Institute (NIRFI), Gor'kiy, and that "a laser is being used as a heterodyne at each station".

Matveyenko [6] reports that an interferometer system, similar to the American system with wide-band registration of discrete signals and high-speed data processing, was produced in the USSR for the radiotelescopes near Serpukhov (Pushchino-na-Oke) and at Simeiz.

1. <u>1969-1970, 230-km base line.</u>

Troitskiy [9] notes that the first "transcontinental" interferometer system with separate signal reception, rubidium frequency standard and data processing with a BESM-4 computer, was produced in the Soviet Union in 1969, and was used in 1969-1970 on a 230-km base line to measure the dimensions of two quasistellar sources at a 3.5 m wavelength, using the Academy of Sciences' Physics Institute antennas (3" antenna lobe widths). These ultrashort-wavelength measurements are described as being the first and only ones of this type ever made on a long base line. The results

* The eighth reference was to a paper by N. G. Basov, a major contributor to the development of laser frequency standards and, later, to USSR laser research and technology, including satellite geodesy applications.

obtained in this experiment are compared with those obtained by W. Donaldson et al (1969) and Bosart et al (1968), but no data are given on base-line length determinations.

Interferometer investigations with separate reception, carried out on a decameter wavelength ($\lambda > 10$ m), were begun at the NIRFI in 1971 [9].

2. Kislovodsk-Zimenki, 1500-km base line.

Information available on the radiotelescope investigations carried out in July-August 1971 on this base line is contained in a paper by Kobrin et al [8] of the Scientific Research Radiophysics Institute (NIRFI). Here, radiotelescopes with identical antennas (2-m parabolic mirrors), set on equatorial platforms, one of which was located at the Mountain Astronomic Station of the Main Astronomical Observatory near Kislovodsk and the other at the NIRFI test area near Gor'kiy, were used to study solar radioemission fluctuations. The paper gives no information on base line length determinations.

3. Zimenki (near Gor'kiy) - Grakov (near Kharkov) 900-km base line.

In February-March, 1972*, the Institute of Radioengineering and Electronics of the Ukrainian Academy of Sciences at Kharkov made

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* Troitskiy [9] gives the dates for these measurements as February-March 1971.

25 MHz-frequency measurements of several quasistellar sources (3C 196, 254, 273, and 144 in the Crab Nebula), using the UTR-2* radiotelescope antennas set up on a 900-km base line between the Gor'kiy (Zimenki) and Kharkov (Grakov) base stations [12]. At Grakov, the north-south arm of the UTR-2 antennas had an effective pattern area of 10^5 m^2. At Zimenki the effective pattern area was 1.5×10^3 m^2 and consisted of 36 half-wave elements oriented along the meridian in two series of 18 dipoles each. Antenna fringes were corrected for site angle and the antennas were linearly polarized. Interstation communication was by teletype. A rubidium frequency standard replaced the quartz standard previously used. Synchronization was effected by television. None of the presently available references dealing with measurements made on this base line contains information on the precision attained in determining the base line length.

4. Byurakan - Simeiz base line (100 km).

In 1972, the NIRFI and the Byurakan Astronomical Observatory (BAO) of the Armenian Academy of Sciences collaborated in the production of an "improved" interferometer system and, in cooperation with the Crimean Astrophysical Observatory, made measurements on the 75-cm wavelength of the 3C 147, 3C 273B(V), 3C 286, 3C 454.3(V) radiosources from the 100-km Byurakan -- Simeiz base line (lobe width, $\Delta = 0.15$ ($d/\lambda = 1.3 \times 10^6$) [9].

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* The general purpose characteristics of the UTR-2 radiotelescope antennas and the problems that are expected to be solved with them are briefly described later in this part of the report.

Again, the only available reference to work carried out on this base line deals with determinations of radiosource dimensions and contains no information on base line length determinations.

5. <u>Serpukhov-Simeiz 1,100-km base line.</u>

The only information presently available on the precision attained in the Soviet Union in determining the coordinates of long base lines with interferometers is contained in a 1973 paper* by B. A. Dubinskiy of the USSR Academy of Sciences' Institute of Radioengineering and Electronics [13]. Although the principal purpose of this paper is to present an analysis of factors affecting the precision of interferometer base line measurements, Dubinskiy uses the results obtained on the Serpukhov-Simeiz base line as an example.

Specifically, Dubinskiy makes an attempt to determine the coordinates of the vector of the interferometer base $\bar{R}$ and those of the observed unit vector of the radiosources (k). His basic assumptions are that the measurement errors are considered to be normal, that their dispersions are specified magnitudes, and that they include nonremovable fluctuations caused by atmospheric inhomogeneities. Auxiliary parameters are introduced in calculating the influence of imprecise matching of heterodyne frequencies. The Cartesian system of geodetic coordinates is recommended and used in the example.

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* Submitted for publication in 1972.

In this example, the coefficients q were calculated for the case in which the number of observation moments j was 3, the latitude of the Serpukhov-Simeiz base was $\varphi_b = 67^\circ$, with observations being made of the W-3, W-75, W-51, and Orion-A radiosources, as shown in the following table (Table 11).

Table 11.

	Base $\varphi_б = 67^\circ$	W-3 $\delta = 61^\circ 53'$	W-75 $\delta = 42^\circ 11'$	W-51 $\delta = 14^\circ 23'$	Ori-A $\delta = -5^\circ 23'$
q_x	0,38	2,7	1,0	0,08	0,01
q_y	0,5	6,6	7,2	7,3	7,4
q_z	0,94	0,8	1,25	1,3	1,2

Here, when the signal -delay error σ_τ was 0.5 μsec, that of the Doppler frequency shift $\sigma_F = 0.8$ Hz, the length of the base line $\bar{R}$ was 1,100 km, and $\Delta t = 4$ hr, the r.m.s. errors in measuring the coordinates of the base were 0.15 - 0.25 km, and those of the radiosources, ~0.5 angular minutes.

B. Intercontinental Long-Base Line Interferometry

In 1968, Professor V. S. Troitskiy, Doctor of Physical and Mathematical Sciences at Gor'kiy State University, submitted a paper for publication in the geodetic literature [1]*, in which he presented a radio-interferometer method of calculating distances between continents and the means by which exact times of observations made at two widely-spaced stations could be synchronized. The method takes into account calculations

* Note: This paper was not published until early 1970.

of delays in signal reception at two stations as affected by diurnal and seasonal fluctuations in atmospheric and ionospheric refraction. On the basis of his calculations, Troitskiy concluded that the principal error in measuring the distance between two radiointerferometers was due to ionospheric and atmospheric refraction and to a random error in the signal train, which could be reduced by longer observation periods. With these extended observation periods, he anticipated that the errors in measuring the distance between stations could be decreased to 1-2 m, providing a relative stability of 10^{-13} of time synchronization was attained - a value attainable with hydrogen maser frequency standards. Troitskiy also pointed out the applicability of his method to synchronous observations of AES - transmitted signals.

The Soviet literature contains very little information on the results obtained during several intercontinental long-base line interferometer studies carried out jointly by U. S. and USSR scientists in the 1969-1971 period:

Late 1969: Crimean Astrophysical Observatory at Simeiz--National Radioastronomic Observatory at Green Bank (USA).
The observations were made at the 6-cm and 2.8-cm* wavelengths.
Results reported: at the 2.8 cm wavelength, an angular resolution of 0".00023 was obtained (width of interference fringe, 0".0007) [6].

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* Troitskiy [9] says 2.7 cm.

1971: Several USA-USSR long-base line interferometer projects:

On a 3.55-cm wavelength:

a) Simeiz 22-m radiotelescope--4.2 m radiotelescope at Green Bank; three antennas, used simultaneously, provided a large body of information on radiosource structures;

b) Simeiz --64-m radiotelescope at Goldstone;

On a 1.35 cm wavelength:

a) Simeiz--37-m parabolic antenna of the Haystack radiotelescope, Westford, Massachusetts; results obtained with a wideband reception system developed in the US, and maser sources developed in the USSR; distance, 7350 km (fringe 0.00036 seconds of arc).

On the 3.55 cm wavelength, the maximum angular resolution obtained was $\sim 0''.0024$ and on the 1.35 cm wavelength, $0''.00012$ [6].

Additional data obtained in the Simeiz-Haystack experiment are provided in a paper written jointly by American and Soviet scientists, published in the Soviet journal Astronomicheskiy zhurnal in 1972, which presents the preliminary results obtained in observing the W 49 radiosource. The maximum angular resolution obtained is reported as being 2×10^{-4} seconds of arc [2].

A 1973 paper by L. D. Bakhrakh et al [14] contains a brief comment on the Simeiz-Goldstone base line to the effect that the base line is about 10,000 km long (angular resolution 0.25 μsec of arc) and that of the six radiosources observed, 3C 273, 3C 84 and J287, gave clear interferences fringes.

C. Radiotelescopes Used in Long-Base Line Interferometry.

1. UTR-2

An abbreviated description of the characteristics of the Radioengineering Institute's decameter-range UTR-2 radiotelescope antennas and the problems expected to be solved with them appears in a paper originally presented by S. Ya. Braude and A. V. Men' at a joint scientific session of the General Physics and Astronomy Section and the Scientific Council on Radioastronomy of the USSR Academy of Sciences, held on 25-26 October 1972 [10]. (For information on the programs expected to be executed with these antennas, see the last section in this chapter, p. 231-232). The general purpose characteristics are as follows: Large effective area of about 150,000 m^2; high resolution, 20' x 20' at 25-MHz frequency; wide scanning area, 150^o for declination and 8-24 hrs for right ascensions, with the possibility for rapid interchange of beam aerials; 5 beam aerials, laid out according to inclination, operate simultaneously to determine ionospheric refraction and increase volume of information; at each aerial, measurements are made at 6 frequencies in the 10-25 MHz range, so that the radioreceiver consists of 30 radiometers. The principal operational mode is modulational. In this mode, pencil beams are formed by means of multiplication of directional patterns in the western antenna, and by discrete phase modulation in the north-south antennas. With all antennas and their sectors, simultaneous receptions can be made in both the modulation and compensation modes, either separately or in different combinations of arrangements.

2. RT-22 radiotelescope (Crimean Astrophysical Observatory).

Information on some of the measures taken to increase the sensitivity in the 3-cm range of the RT-22 radiotelescope at the Crimean Astrophysical Observatory is reported in a paper* by L. D. Bakhrakh et al of the Institute of Space Research, USSR Academy of Sciences [14]. Specifically, the paper describes two amplifiers (2.8 and 3.55 cm wavelengths), in which the high-frequency portion consists of a ruby maser. An yttrium ferrite rectifier in the amplifier reduces return-wave noise by 65-70 decibels. High phase stability is attained by small magnets with superconducting windings. Superconductive shields are used to reduce scattering and to improve magnetic field homogeneity. The amplifiers operate in 5-liter metal cryostats at the temperature of liquid helium (4.2° K), continuously operating for 10-hr periods without addition of helium.

Minimal antenna noise is achieved by a Cassegrain system (diameter of hyperbolic mirror, 1.5 m; equivalent focal length, 140 m; second focus, 200 mm from base of parabolic mirror; 2- mirror system

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* Submitted for publication in 1972, published in 1973.

used to allow use of small exciter). After the antenna is tuned, the widths of the directional pattern at half-power points in the azimuthal and position angle planes, are 6!25 and 6!35, respectively. The effective area of the antenna is 185 $\pm$ 10 m^2 and the calculated usable surface is 0.56. The total antenna noise temperature in the zenith direction is 14 $\pm$ 4° K and that of the incoming space and atmospheric radioemissions, about 6° K (8 $\pm$ 4° K for the antenna alone). At angles of $\pm$ 1°, the scatter field of the antenna has a noise level of the order of 45-50 decibels.

As a result of these improvements, radiotelescope sensitivity was improved to the extent that the overall noise temperature was 80° K for a position angle of 30° and dropped to 70° K at larger angles. Note: The utilization in 1971 of this improved equipment on the Simeiz-Goldstone base indicates that the above information is outdated by at least two-three years.

D. USSR Frequency Standards Used in Long-Base Line Interferometry.

A paper by L. R. Kogan of the Institute of Space Research of the USSR Academy of Sciences, published in 1973, reports the results of investigations of three of the frequency standards used in the USSR in long-base line interferometry and the results are compared with the USA standard, HP5065A, used during the joint USA-USSR long-base line experiments carried out in 1969 and 1971 [3]. In Kogan's study, optimal times of signal accumulation are calculated as functions of short-term heterodyne signal stability and frequency for the following four frequency standards:

1. Ch 1-44, hydrogen (USSR)
2. Ch 1-43, rubidium (USSR)
3. Ch 1-50 (USSR)

HP5065A (USA)*

The dependence of optimal signal accumulation time on frequency for the four types (3 USSR, 1 USA) of heterodynes is illustrated in the following graph (Fig. 48).

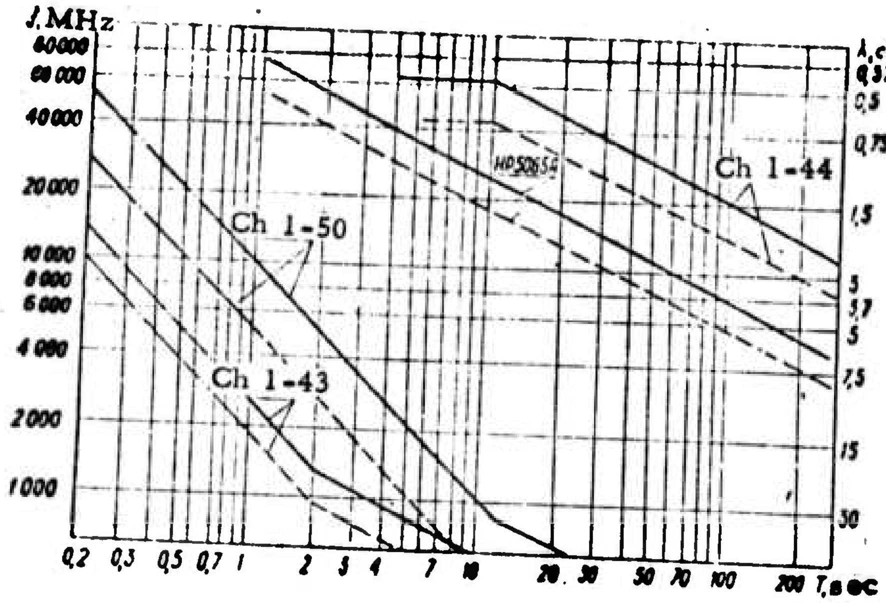

Fig. 48. Dependences of optimal accumulation time on frequency for the four types of heterodynes.

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* Used in joint USSR-USA 1969 and 1971 long-base line interferometer measurements.

The dependence of the short-term stability of the frequency $\sigma_{\Delta f/f}$ on averaging time determined for the four frequency standards is given in Fig. 49.

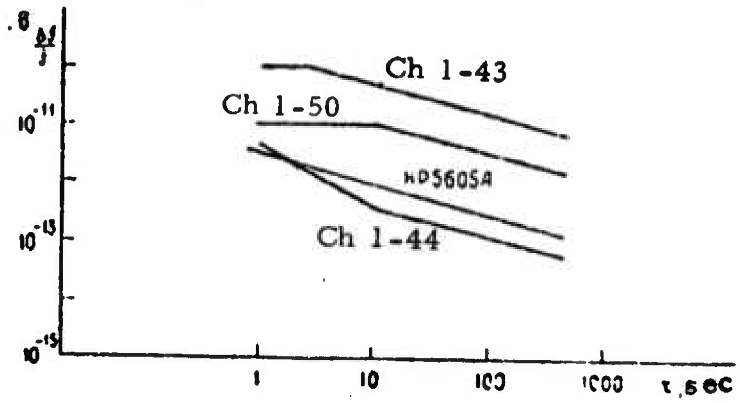

Fig. 49. Dependence of short-term stability of the $\sigma_{\Delta f/f}$ frequency on averaging time.

E. Precision of Radioastronomical Measurements Made with Long-Base Line Interferometers.

Estimates of the precision with which determinations of the coordinates of the pole, declinations and hour angles (right ascensions) of point radiosources, and the calculation of sidereal time can be attained with long-base line interferometers, are made in a paper by N. S. Blinov and Ye. N. Fedoseyev, published in 1973 [4]. The calculations are based on the assumptions that the observations are made on a 21-cm wavelength, that the precision of determining $\Delta \ell$ is 10 cm, and that high-precision atomic frequency standards are used at both interferometer stations.

The following precision estimates are derived:

a. For latitude variation determinations - the difference in radiotelescope latitude rarely exceeds 10 cm, and the precision of the determination of $\Delta\varphi_1$ (t) is ~20 cm;

b. For polar coordinate determinations - if the reference generators are not absolutely synchronized, their errors constitute an additional error $d\tau c$ in determining $d\frac{(\Delta l + \Delta l')}{2}$, where $d\tau$ is the synchronization error and c is the velocity of light. If it is necessary that $d\tau c < 20$ cm, $d\tau$ should not exceed 6×10^{-10} sec.

c. For declination determinations - error depends on the declination and may amount to 0.″1;

d. For determination of right ascensions - error of ~$0.^s001$ for 50°-70° zones of accumulation, its precision decreasing with an increase in inclination.

An investigation made by V. I. Shiskov [5] of the Lebedev Physics Institute on the influence of radiowave diffraction in inhomogeneous and interstellar plasma on long-base line interferometer resolution, demonstrates that for both the case of low-level amplitude modulation of the incident penetrating radiowaves into inhomogeneous media, and for the case of high-amplitude modulation of radiowaves passing through a randomly-reflecting medium, the angle of radiowave scattering is not limited by interferometer resolution. This makes possible interferometer measurements of radio source dimensions from base lines longer than $\lambda/2\pi\theta_0$.

Shishov also estimates interferometer parameter limits and observation conditions applicable to extragalactic radiosources in the high galactic latitudes.

The use of long-base line interferometers with synthetic apertures in measuring the positions of radiosource noise has been investigated by V. V. Sazonov and V. V. Karavayev of the Radioengineering Institute, USSR Academy of Sciences [7]. In this paper, formulas are derived for the determination of the maximum limits of this type of system for the general case of the random spatial movement of both receiving positions on the base line. Their solutions demonstrate that the problem reduces to the computation of moments in time as determined by the type of trajectory and the relative position of the observed object.

F. Future Developments Anticipated in Long-Base Line Interferometry.

Two recent papers are available, in which the authors express their views on the future developments in and the problems expected to be solved with long-base line interferometry. The first paper, by Braude and Men' [10], deals specifically with the use of UTR-2 antennas, mainly in solving astronomical problems, i.e., 1) execution of a survey of discrete and extended sources of space radioemissions to enable compilation of their spectra, determine their angular dimensions and radio brightness in the decameter range; 2) measurement of the radio emissions of the quiet sun and solar flares; 3) observations of pulsars and the occultations of space radiosources by the moon; 4) search for nonthermal radioemissions of the planets in the solar system; 5) study of the refraction, attenuation and fluctuations of radiowaves in the ionosphere; 6) compilation of charts showing the distribution of space radioemissions, particularly where they are absorbed in ionized clouds; and 7) to continue operations, now underway, for building several UTR-2-type long-base line interferometers for measuring radiosource dimensions.

The developments foreseen by Matveyenko in the second paper [6] are in general agreement with the programs postulated by Braude and Men'. Matveyenko, however, anticipates that long-base line interferometer measurements will, in the future, be at the 8-mm wavelength. In addition, he believes that the 1.35-cm wavelength is preferable for investigations of the stars and the planetary systems, and that a space telescope with a small antenna could be used, with subsequent observations being at the 18-cm wavelength. More significantly, insofar as satellite geodesy is concerned, he proposes that interferometers be installed in artificial satellites launched into elongated orbits. Finally, he anticipates that the precision with which the distances between radiointerferometer antennas will be measured in the future will be improved to "several tens of centimeters, a precision adequate for continental-drift determinations".

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Appendix A

Data Available for 1961 ECHO-I Observations (date, satellite observed, U.T., ΔT, $\alpha 1950.0$, δ 1950.0.

1. Pavlenko, P. P. (Data recorded at the Astronomic Observatory, Khar'kov University-station no. 1060). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 36, 1963, p. 30-31. Dates of observation: April 13 and 30; May 2, 6, 13, 16, 17, 1961. Accuracy of time determination, $\pm 0\overset{s}{.}01$; position accuracy, ± 3-5".

2. Kadyrov, A. K., A. G. Rakhimov (Data recorded at the Tashkent Astronomical Observatory-station no. 1075). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 38, 1964, p. 32-35. Dates of observation; April, 6, 18, 21, 23, 24, 27, 28, 29, 30; May 2, 3, 4, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23, 24, 27, 30, 31, 1961. Internal convergence of the determination of moments of time was less than $0\overset{s}{.}003$; the r.m.s. error in satellite position, calculated from the difference in satellite position from the first and second set of three reference stars, was ± 7 in α and ± 11" in δ.

3. Kadyrov, A. K., A. G. Rakhimov (Data recorded at the Tashkent Astronomical Observatory-station no. 1075). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 39, 1964, p. 22. Dates of observation: April 21, May 12, 1961. The r.m.s. error of one satellite position, calculated from the difference in satellite position between the first and second set of three reference stars, was ± 7" in α and ± 11" in δ.

4. Syshchenko, T. Ye., B. A. Firago (Data recorded at the Glavnaya Astronomicheskaya Observatoriya (GAO), Pulkovo - station no. 1039). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 48, 1966, p. 12-15. Dates of observation: April 17, 19, 20, 22, 23, 26, 27, 28; May 3, 9, 16, 17 1961. Moments of observation times were reduced in the UT_2 international system. The "internal" precisions of satellite position and time were 2."1 and $0^s.00010$, respectively, and the "external" precisions, 4."1 and $0^s.0030$.

5. Zhebrovskaya, L. S., P. P. Pavlenko, R. M. Shut'yeva (Data recorded at the Astronomic Observatory, Khar'kov - station no. 1060). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 48, 1966, p. 16. Dates of observation: April 24, May 2, 6, 13, 1961. Each satellite position was calculated from two sets of three reference stars. The timing precision was $\pm 0^s.01$ and the positional precisions for α and δ were ± 3".

6. Panova, G. V., T. Ye. Syshchenko (Data recorded at the Glavnaya Astronomicheskaya Observatoriya, Pulkovo - station no. 1039). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 51, 1968, p. 45-47. Dates of observation: April 17, 22, 23, 26, 27, 28; May 3, 4, 16, 17, 1961. Moments of observation times were reduced in the UT_2 international system. The precision of determining satellite position was ± 4", and that of time registration, $\pm 0\overset{s}{.}003$.

Appendix B

Data available for 1963 ECHO-I Observations, (date; U.T.; mean coordinates; α 1950.0, δ 1950.0; true coordinates α, δ; number of reference stars).

1. Dinescu, A., and M. K. Kirshmaru (Data recorded at the Astronomic Observatory, Bucharest - station no. 1131). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 42, 1964, p. 24-25. Dates of observations: June 4, 8, 9, 1963. The observations are synchronous with Potsdam. The rectangular coordinates of the satellite and the reference stars were made with the Zeiss coordinatograph (accuracy of micrometer readings, ±0.001 mm). The right ascensions and declinations (1950.00 epoch) were selected from the Boss catalog.

2. Reyse, H. (Data recorded at Potsdam-station no. 1181). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 48, 1966, p. 24-25). Dates of observation: June 4, 8, 9, 14, 1963. Data tabulated: Time (UT), α 1950.0, δ 1950.0. Results obtained: r.m.s. error in determining satellite position, ± 3-±4 [sic]; r.m.s. error of time registration, ± 4-5 msec. These data are positively identified as being a part of the "Optical Observations of Artifical Earth Satellites" program.

3. Kadyrov, A. K., A. G. Rakhimov (Data recorded at Tashkent Astronomical Observatory - station no. 1075). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 42, 1964, 21-24*. Dates of observation: May 22, 24, 25, 26, 29, 30 and June 1, 2, 3, 5, 9, 11, 12, 13, 14, 1963. Gives data on time of observation (UT) and for α 1950.0 and δ 1950.0. Results obtained: The r.m.s. error of a single satellite position, calculated from the difference in satellite position between the first and second set-of-three reference stars, was ± 9".

4. Kadyrov, A. K., A. G. Rakhimov, M. R. Eshmatov (Data recorded at Tashkent Astronomical Observatory - station no. 1075). Akademiya nauk SSSR. Astronomicheskiy sovet, Byulleten' stantsiy opticheskogo nablyudeniya iskusstvennykh sputnikov Zemli, no. 48, 1966, p. 20-23. Dates of observation: June 1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 26, 27, 28, 29, and July 1, 1963.

As with item 3 (above) the data from this station are not specifically mentioned as being a part of the major program of 1963 observations of ECHO-I; however, observations at this station may be among those made at the unnamed participating Central Asian stations. Gives data on time of observation (UT) and for α 1950.0 and δ 1950.0. Precisions of results are not reported.

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* This station has not been definitely mentioned in the literature as being a participant in the 1963 ECHO-I observations, but it may be one of the "stations in Central Asia", mentioned by Shchegolev (Byull. no. 36, 1963, p. 21-22. See also 4, below.

Appendix C

Comments on the Training and Education of the Staffs of Soviet Satellite Observation and Tracking Stations.

In reviewing and analyzing the voluminous astronomic, geodetic and physics literature pertinent to the scope of the present report, the author encountered numerous papers (Soviet and East European), which contained information on the numbers of scientific and technical personnel engaged in East European and Soviet satellite observation and tracking programs. These same (and other) sources also provided scattered and incomplete data on the training and education of these personnel.

An attempt to search for and analyze information on these topics was considered to be beyond the scope of this report. However, in view of the fact that no comprehensive review of this subject appears to have been published in the Soviet Union and because no evaluation of Soviet satellite observation programs can be considered complete without some estimate of the current and future potentials of the personnel involved in these programs, a preliminary and admittedly incomplete, overview may be of interest to some readers.

As is frequently the case in the USSR, reporting of scientific data, especially those of potential significance in matters of a military nature, is much more complete and informative in the early stages of development than is the case in the later and more sensitive stagec. This phenomenon is perhaps attributable in part to the fact that information dealing with the details and results of early operations are less significant or sophisticated or that, as might very well be the case in reporting the results of Soviet satellite observations, the first flush of their success in launching the first satellites led to the publication of more detailed information than is normally the case. Indeed, the reason may well be that such information had to be omitted because of the ever-increasing volume of data available on more important scientific and technical subjects.

Whatever the reason or reasons, the fact is that statistical data on the number and location of Soviet satellite observation stations in operation, the type and number of personnel staffing them and the results obtained by them occur most frequently in Soviet reports published during the years immediately after the launching of the first Soviet satellite. For the most part, information on later activities is found in review-type articles and in symposium and conference proceedings, but rarely in scientific or technical reports. On the other hand, papers dealing with training and educational programs are much more frequently published in their scientific and technical journals (Soviet educational journals have not been reviewed).

For purposes of the present report, the following data on Soviet scientific and technical personnel and on their education and training have been selected as representative of the early (1958-1960), middle (1966) and "current" (1972) periods of development of the Soviet satellite observation programs.

According to a 1958 report [1], regular observations, "carried out by 10,000 observers", began on 4 October 1957. By 1 August 1958, the following data had been sent to computer centers from the 70 visual and 25 photographic observation stations in continuous operation at that time:

Table 12.

	Satellite 1 and its rocket	Satellite 2	Satellite 3	Satellite 3 rocket
Visual observations	1289	4420	978	4282
No. of photos made with small-format cameras	23	192	3	67
No. of photos made with NAFA-3C cameras	11	265	22	262
No. of photos made with astronomic instruments	5	10	1	19

In 1960, the Astronomic Council published a report [2], which summarized the status of the visual and photographic observations of AES for the 1957-1959 period. During this period the number of stations making visual observations had been increased to 74 and those making photographic observations, to 26. (Note that in some localities the stations performed both types of observations).

As of 1 January 1960, the staffs at the visual stations numbered 2500-3000 students and about 300 instructors and laboratory technicians working in the physics and physics-mathematics departments of state universities and pedagogical institutes. At a few stations (Dnepropetrovsk, Bukhara, for instance) students in the upper grades of the secondary schools also participated. In addition, special courses, initiated in 1957 at the Institute of Physics and Geophysics at Ashkhabad, had trained 130 students specializing in astronomy and physics as instructors for satellite observation work.

By this time (1960), the detailed breakdown of observations by type (visual and photographic) was no longer reported, as the following table shows (Table 13).

Table 13

Object observed	No. of satellite passes observed	No. of individual observations made	Observation intervals
Satellite 1	78	119	4 October 1957 - 4 January 1958
Satellite 1 rocket	552	1170	4 October - 1 December 1957
Satellite 2	1367	4482	3 November 1957 - 14 April 1958
Satellite 3	8978	25,191	15 May 1958 - 6 April 1960
Rocket of satellite 3	4084	14,303	15 May - 3 December 1958

Statistical data for both the visual and optical observation programs for 1962 are given in a paper by Ye. Z. Gindin et al [3]. For the visual programs, the emphasis was on the accuracies with which the observed positions of the AES agreed with the precomputed positions. Much more data are given for the photographic programs, and they include information for the 1958 - 1959 period, for 1960, 1961 and 10 months in 1962 (See Table 14).

Work of Soviet stations photographically observing artificial earth satellites (using NAFA-3c/25 cameras).

Table 14

Years	No. of actively participating stations	No. of objects observed	No. of negatives obtained	
			Total	Suitable for processing by precise methods
1958-1959	10-12	3	1979	1074
1960	15	8	1907	1375
1961	23	14	6813	4473
1962 (10 months)	27	23	3931	3105

A paper by A. A. Blagonravov and Yu. I. Zaytsev [4] gives the following data for the 1966 work of Soviet regularly-observing optical tracking stations (visual, photographic, photometric):

Table 15

No. of regularly participating stations		Total no. of observations	No. of satellite passes	No. of negatives obtained	No. of satellites
Visual	Photographic				
61	25	150,000	30,000	~7,000	200

A paper published in 1972 [5] reports that the Moscow Institute of Geodetic, Aerial Mapping and Cartographic Engineers (MIIGAiK) is involved in a major project in compiling new student manuals and programs that are designed to educate specialists who will be able to solve problems in gravimetry and the figure of the earth, which must be faced by 1980 and later. Curriculum emphasis is heavily weighted toward courses in mathematics, physics, and computer technology. The authors also note that the first students in the new training specialty, "Space Geodesy", started at the MIIGAiK in 1968, will graduate in 1974.

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APPENDIX D

USSR Program for the Evaluation of Potential Sites for New Astroclimatic Stations.

As mentioned in Part II of this report, since 1957 several of the largest astronomic observatories in the Soviet Union have been deeply involved in satellite observation and satellite geodesy programs, their operations ranging from organizational and administrative leadership to the practical implementation of and participation in national and international projects. In recent years, as developments in laser, radioastronomy and radiophysics technology have been applied to satellite tracking and to space triangulation for national and international network construction, these same (and other) astronomical observatories, in cooperation with meteorological, radioastronomic and radiophysics observatories or institutes, have become involved in research and development programs that have been both directly related to satellite observation and geodesy and to programs that are more marginal in character, but which have some bearing on their implementation or precision. Examples of this type of project include the SPIN and INTEROBS programs (meteorological-climatological factors affecting geodetic observation precision), and a vigorously-pursued, long-term USSR program for the identification and evaluation of potential sites for astroclimatic observatories, i.e., those sites which would offer optimum "seeing" conditions. Such sites, equipped with the appropriate instrumentation complex (astronomical telescopes, meteorological instruments, laser-ranging equipment, satellite cameras, radiotelescopes and long-base line interferometers), such as is the case at the Crimean Astrophysical Observatory and its related facilities, could serve a broad spectrum of scientific research purposes, including satellite geodesy. Since this program may result in the establishment of new stations, which could (or have?) become potential base stations in the USSR geodetic networks, a brief description of the aims, current status and the recently published results of this program is presented as background data for future follow-up studies.

More or less regular observations to determine the astroclimatic characteristics of some of the potential sites in the USSR (principally in the main mountain chains of south central USSR) for establishing new astroclimatic observatories, began in 1953 at the suggestion of V. A. Krat of the Astrophysics Laboratory of the Azerbaydzhan Academy of Sciences (now the Shemakha Astrophysical Observatory). By 1954, the Main Astronomical Observatory (GAO) and the Volgograd Municipal Planetarium had become active in the program, field expeditions being sent to several locations. During this early period and into 1961, the observational programs and instrumentation used by the various participants apparently had been poorly standardized and coordinated. These faults were discussed at the 1962 All-Union Conference on the Optical Instability of the Atmosphere of the Earth, with the result that a resolution was passed which called for the preparation of and adherence to uniform data reduction and processing procedures. The Group for Astroclimatic Studies of the Mathematics Institute, Siberian Branch of the USSR Academy of Sciences, was charged with the collection and systematization of all available data. The results of their efforts covering the data for only one year (1953) was published in 1964 [1] in the form of a catalog.

Examples illustrating the increasing amount of field and laboratory work involved in this program during the 1961-1970 period are described in two recent papers. In the first of these, V. S. Shevchenko gives a detailed account of a series of expeditions carried out through the efforts of the Astronomical Institute of the Uzbek Academy of Sciences during the 1961-1968 period in the Chatkal Range of the western Tien'-Shan Mountains, in the Pamirs (Chechektakh) and on Sanglok Mountain in the Tadzhik SSR [2]. The second paper, written by S. B. Novikov and P. V. Shcheglov, summarizes the results of a 1968-1970 project carried out by the Shternberg State Astronomic Institute (GAISH), to find a suitable site for the installation of a 1.5 m reflector telescope [3].

Shevchenko's paper [2] contains a well-documented historical summary of the 1961-1968 expeditions of the Uzbek Astronomical Institute, the types of observations made (meteorological and optical) and the instruments used, methods of data reduction and processing, and identifies several sites suitable for astrophysical observations, the most favorable being Mt. Maydanak, Uzbek SSR ($\varphi = 38^\circ 40'$, H = 2760 m) on a spur of the Western Alai Mountains. Comparison of the Institute's data with those obtained by other organizations and for other areas of the USSR, South American and the U.S.A., indicated that two other Uzbek sites were nearly as good as Mt. Maydanak: Angren Plateau and Naugarzan. Chechekty (Byurokan

Astronomic Observatory), and Sanglok (Tadzhik SSR) were also found to be very suitable.

Novikov and Shcheglov [3] report that on the basis of the studies mentioned in Shevchenko's paper, the Shternberg Astronomic Institute made detailed photometric studies in the 1968-1970 period at two of the sites recommended by Shevchenko--Mt. Maydanak and Sanglok--using two special dual-beam photometers that were designed and built at the Institute. Star images obtained with these instruments had an average image diameter of 0."6 at Sanglok and 0."7 at Mt. Maydanak, i.e., were comparable and confirmed good "seeing" conditions at both sites.

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